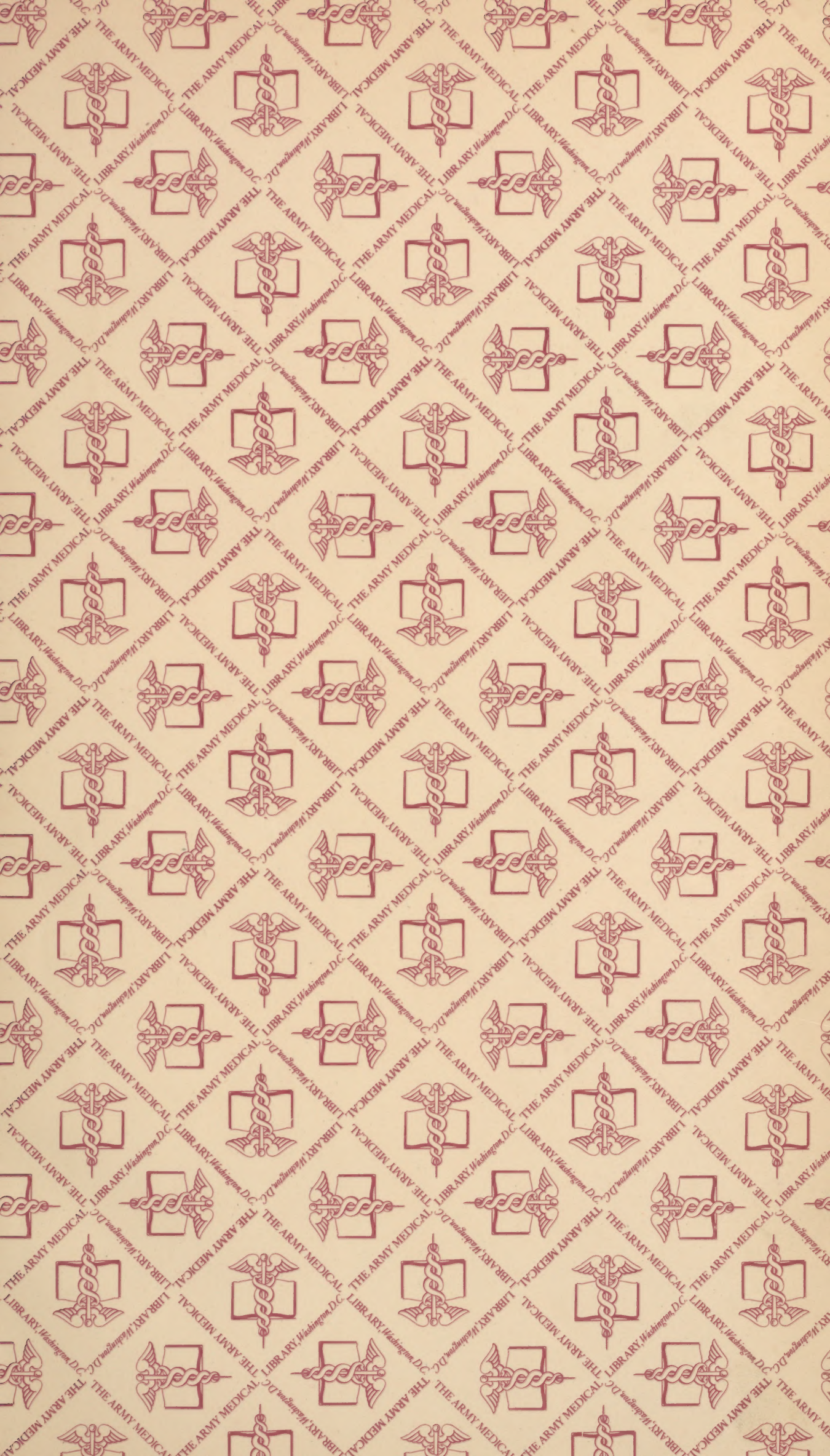
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CHAPTER IV.

The Hazards of Marrow Nailing.

The surgeon who for the first time is confronted with the problem of marrow nailing is quite concerned when he sees how big the nail appears in the X-ray picture as it lies in the bone. It must be noted, that the X-ray picture does not reveal the true lamella shape of the nail and it appears that the nail fills the marrow cavity completely. If the surgeon does not have the opportunity to observe the patient, the X-ray picture will give rise to considerable apprehension with respect to this method. Marrow-nailing judged under these circumstances will appear the most barbaric approach so far practiced in the treatment of bone fractures. In reality, this method causes the least amount of trouble to the patient and it causes the least amount of ill-effects to the muscles, joints, tendons, and vessels and in this respect is superior to any other method of healing bone fractures. This factor is most important, since the muscles, joints, etc. are the most important part of the limb which the body is often unable to replace. The tissue of the bone, however, may be built up by any type of mesenchymal tissue. The severe damage to the muscles and other soft parts caused by a prolonged immobilization or by a prolonged extension treatment are avoided from the very beginning. The disagreeable aspects of a long convalescence are overcome by this method.

By the use of the marrow nail the injury of a bone fracture is limited to the bone and the marrow. The question arises as to what price must be paid for this achievement. Is it not dangerous to introduce such a large metal foreign body into the body? What are the chances of a mishap during the marrow nailing operation? Does a bone so treated heal properly?

There is no doubt that marrow-nailing causes a severe damage to the marrow. Although the nail is not entirely solid and does not fill the entire lumen of the bone, it still causes a considerable destruction of the medullar substance the size of which at least corresponds to the volume of the marrow nail given in the previous chapter.

Now the question arises whether or not this damage or the presence of such a relatively large quantity of metal in the bone does not interfere with the callus formation or even completely stop it. As was demonstrated in the previous chapter this is not the case. The marrow tissue has no influence on the formation of periostal callus which has the most important function in callus formation. The formation is not hampered but on the contrary in many cases is even stimulated. KUENTSCHER went so far as to completely fill the marrow canal of fractured bones of dogs with solid nails or KIRSCHNER wires. In all cases the fractures healed with a strong formation of callus in very much the same way achieved by lamella shaped nails. Even though the bone did not contain any marrow for more than 1½ years because the marrow cavity was entirely filled with glass rods or non-oxidizing steel wires the callus formation proceeded in the normal way (see chapter III).

Since the introduction of marrow-nailing many lively discussions have considered the question whether or not the callus formation is disturbed in man. KUENTSCHER was of the opinion that the callus formation was even stronger than in all other methods hitherto known. EHRLICH, A. W. FISCHER, HEIM, SPRENGELL and others shared his opinion. BOEHLER was also of the same opinion, but after the careful study of 500 X-ray pictures he came to the conclusion that this is not true and that under certain circumstances the marrow nail has an impeding effect. This was also the conclusion of RAISCH and SCHNEIDER. MAATZ checked in 1943 the records of the Kiel clinic comprising 300 cases and he noted no increased callus formation except in 5 cases which concerned juvenile patients. RIEDER, in his hospital had comparative investigations made of cases treated by the old methods and an equal number of marrow nailings and concluded that no discernible difference can be found.

In this connection it is important to come to a clear understanding of the definitions. In Chapter III increased callus formation was synonymous with increased regeneration of the bone, that is to say an increased formation of germinal tissue. This constitutes the first phase of bone healing, which is also characterized as the acid phase (see chapter II). We must clearly distinguish between the first phase and the second phase which involves bridging over of the fracture by bony substance or by the development of a pseudarthrosis.

That which has happened in the first phase becomes perceptible in the X-ray picture only after the second phase has begun, that is to say after the deposit of calcium salts. Palpation is not a satisfactory method for a comparison. There is no exact unit for the measurement of the amount of callus. It can only be estimated by frontal and lateral view of X-ray pictures. As a matter of fact any estimate is subjective. It must furthermore be borne in mind that the regenerative power depends largely on general and local conditions. It is much more pronounced in juvenile than in advanced age. It also depends on the state of nutrition and among our patients is obviously on the decrease due to the nutritional deficiencies of war and post war times. Locally the quantity of newly formed callus depends on the periosteal conditions in places where a thick periosteum is found, the callus formation will be incomparably stronger than in those places where the periosteum is very thin. The influence of the muscles is also evident. The stronger the muscles in the vicinity of the fracture, the more pronounced will be the callus formation. There is no doubt that in this case the increased vascularization plays a certain part. Thus fractures of the shaft of the femur form good callus, while the neck of the femur on the other hand forms little callus. The same can be said of the condyles of the femur. Similar conditions are observed on the tibia. The callus formation of the shaft of the tibia is, however, inferior to that of the shaft of the femur. The shaft of the fibula always reveals an abundant formation of callus because it is surrounded by a thick coat of muscles. At the head of the tibia and at the malleoli callus formation is less pronounced. The ribs and the clavicle show a pronounced callus formation.

The radius and ulna on the other hand show relatively little callus formation. The short flat bones such as the carpal bones and the bones of the skull display very scanty formation of callus. An increased amount of callus is formed if there is a considerable friction of the fragments of the bone. BOEHLER mentions in this connection the fissural fractures of the second and third metatarsals. These are bridged over by a small amount of periosteal callus if they are immobilized in a plaster cast. If these fractures, however, are not immobilized by a plaster bandage and are allowed to move intensely, an abundant formation of callus will be observed.

The quantity of the newly formed germinative tissue also depends largely on the shape of the fracture. Comminuted fractures show a far stronger callus formation than fine fissures, because more bone substance was irritated mechanically and more bone substance has been destroyed. Last but not least the position in which the fracture heals is of great importance. A fracture of the shaft in the middle of the femur for instance produces much more callus if it heals with a considerable lateral displacement and shortening, than if it heals with little displacement.

All these factors have to be considered when comparing the amount of callus formed with marrow nailing and with the plaster cast or extension treatment. It is therefore, not sufficient to compare two femur fractures of equal appearance. The patients rather must be of about the same age and in a similar state of nutrition. The X-ray pictures must be made with rays of the same intensity and be developed to the same density etc. The position of the fragments is very important. Since the fracture cleft is reduced in the marrow-nailing method to a fissure, it will be necessary to use comparably good positions with other methods for comparison. These perfect reductions as obtained by marrow nailing are rarely seen in other methods. The more exact the reduction of the fracture, the less callus is produced. At the same time a smaller quantity of germinative tissue is required to cement the fragments.

It would be a serious mistake to conclude from the mere presence of pseudarthrosis that a lesser amount of callus was formed. Even in case of an abundant formation of callus pseudarthroses may develop under unfavorable mechanical conditions as has been demonstrated in chapter III. In the majority of cases of pseudarthrosis there was even an abundant formation of callus (see chapter VI).

Unfavorable mechanical conditions for the callus may also develop after the marrow nailing, particularly in those cases where no stabile osteosynthesis has been achieved, that is to say if the nail chosen was too short or too thin. The blame for these shortcomings cannot be laid upon the method and these cases are of course, unsuitable for comparative evaluations. In the last mentioned cases a very essential factor is lacking, namely the advantage of the unrestricted motility of the limb and in conjunction with it the considerably improved vascularization.

There is no doubt that in man the formation of callus is provoked by the mechanical and chemical stimulus of the marrow nail, as has been described by KUENTSCHER. (See chapter III). This becomes particularly evident when nails with a high iron content are used. In the beginning KUENTSCHER used nails which contained such a high percentage of iron that they were magnetic. The callus formation thus induced extends far beyond the site of the fracture and over the entire length of the nail. It decreases in the area of the trochanter where even in normal conditions the periosteum cannot form a similar amount of callus. At the spots, where the non-oxidizing V2A coating was damaged thus causing rust, we observe a considerable periosteal apposition in the sense of a callus formation corresponding in location to these damaged spots (see illustration 37). These phenomena have been described by EHRLICH, SPRENGELL, BOEHLER and others. In one instance described by SPRENGELL the point of a guide rod made of ordinary steel broke off and was left in the marrow cavity. In this spot which was far distant from the fracture site a thick periosteal callus was formed. In those cases where the point of too thin a nail due to the particular conditions of the fracture was pressed against the corticalis we also observe a corresponding reaction of the periosteum. The same applies to the fracture cleft caused by the movements of a nail too thin in size. It may, therefore, be safely maintained that in man callus formation occurs without a bone fracture.

In some instances the callus attains the dimensions of a tumor. Due to its large dimensions it requires a longer period for "dis-acidification" than a normal amount of callus. Therefore it needs more time for calcification and it is without exception softer than normal callus of the same age, that is to say the bulky callus is, despite its volume, less strong than the normal one. In the case of such an enormous callus formation in a fracture of the femur KUENTSCHER had withdrawn the nail as early as 8 weeks after the operation and then a fracture of the callus promptly occurred (see chapter V). This case has also been described by A.W. FISCHER. It is not out of place to mention in this connection that a fracture of the femur treated by plaster or extension bandage and also prematurely exposed will not have the necessary strength to resist even an atrophied musculature. In the case described above the muscles were not enfeebled at all since the patient had used the leg walking about. The apparent conclusions to be drawn from these facts with regard to the proper time for the removal of the nail are discussed in the following chapter. Sometimes the acidification of the excessive callus attains such a degree that an edema of the adjacent soft parts is initiated. This process is painful to the patient and the continual shifting of the ion equilibrium causes serious damage to the tissues and impedes secondary healing (see chapter III). These cases are rare and the damage is generally not extensive. In these cases we have to accede to BOEHLER's opinion who designates this callus as noxious. He refers to this kind of callus as "irritation callus". As callus is always produced by irritation, particularly of the bone (chapter III), it is understood that "irritation callus" means callus due to excessive irritation. It often appears

on the X-ray picture that the fracture cleft extends into the soft callus. This had no influence on the final healing and is by no means synonymous with a beginning pseudarthrosis. It may generally be said that the callus solidifies quite satisfactorily and shows good healing results if protected from injuring forces. This is the case with a stable osteosynthesis. For the reasons mentioned above the formation of this callus requires more time. This is of no importance since no harm is done if the nail, which accounts for the stability, is left in position a few months longer. The nailed extremity can be used without restriction and the patient is not hampered in the performance of his occupation.

Eventually it may be said that the whole callus problem is primarily of theoretical rather than of practical interest. It is of no bearing whether the results of future more detailed and exact tests will have a different outcome, that means whether with marrow nailing more, less or exactly the same amount of callus is formed as with the other methods of treatment. The experience gathered so far in several thousands of marrow nailing operations has shown that the amount of callus, though small due to the exact reduction of the fracture, is always sufficient if the nail is not removed too early. No cases of pseudarthrosis have become known with fresh bone fractures after a successful marrow nailing operation, that is if a stable osteosynthesis was achieved.

Special caution is advised in the attempts to produce a copious formation of callus by mechanical irritation, as by the use of special metal formulas, to avoid that no chemical injuries of the soft parts adjacent to the callus occur.

Impairment of the Bone Marrow.

It is common knowledge that the bone marrow is not a highly differentiated tissue and is characterized by a remarkable regenerative power. WALTERHOFER and SCHRAMM have published their experiences in this connection in 1921. In many cases of pernicious anemia SCHRAMM has scraped out the entire marrow cavity with the avowed object of stimulating the formation of blood and bone marrow. He was able to observe a complete and extremely rapid regeneration of the bone marrow after 42 days. This problem has thus been settled prior to the invention of the marrow nail. The question arises whether or not this damage to the marrow may have a bad effect on the blood count, or in other words, if the metal of the nail does not produce a change of the blood count by irritation. In his first 100 marrow nailing operations, KUENTSCHER was unable to detect a change of the blood count, apart from an increase of the eosinophile cells. This increase amounted to as much as 9 % and could be observed only in patients below the age of 40. Above this age such a change was no longer observed. The number of eosinophile cells in all

cases promptly dropped to normal upon removal of the nail. O. RAISCH reported about a 22 year old woman, suffering from a pseudarthrosis of the femur, which was nailed by him 18 months after the accident. Three weeks after the operation a hemoglobin drop from 85 % before the operation to 45 % was observed which made 5 blood transfusions necessary. RAISCH traced this phenomenon back to the nail in the marrow cavity. This is, however, an isolated case and all his other marrow nailing operations did not reveal similar symptoms. After each transfusion of 250 cc. of blood of the same group, the hemoglobin value rose to 75 % and dropped to 50 % in the course of another two weeks. Normal values were restored upon removal of the nail. KREINSLEHNER observed in one case of marrow nailing a conspicuous pallor of the patient which disappeared upon removal of the nail. No blood count was made in this case. In 1943 GLADKOWSKI examined 70 patients, nailed by KUNTSCHER, by means of sternal puncture. These cases included closed fractures, marrow nail osteotomies, as well as marrow nail treatment of recent and old gunshot fractures. Many of these cases were infected and temporarily showed a high pyrexia. The findings did not materially differ from what is generally found in similar cases. In 1944 SLANY published his observations concerning conspicuous changes of the blood count in some of his cases. He observed a considerable long lasting increase of the reticulocytes. In healthy persons, their number is 3 per 1000 red blood corpuscles. Some authors, however, found higher figures, such as 5 or 6, or even 11.7 per 1000. SLANY observed 12 to 21 per 1000 in fractures of the long bones, especially in femur fractures. After marrow nailing an increase to values of 28 to 57 per 1000 was not infrequently observed. This value is subject to considerable variations. A return to normal conditions sets in immediately upon removal of the nail. This phenomenon may have a variety of explanations. Through its presence in the medullar cavity the marrow nail, as a local source of irritation, either causes the release of reticulocytes from the nailed bone marrow to the vessels, or the irritation due to the nail is transmitted from the affected bone marrow to the other parts of the hemopoietic system with the result of a general reaction. SLANY finally mentions the possibility of a specific effect of the iron of the nail acting by catalysis and of an ion effect of the steel as the causative factor for the general reaction.

SLANY has attempted to make a practical use of this phenomenon, in that he introduced a nail into the femur of a patient suffering from pernicious anemia. The result was that the number of reticulocytes which amounted to 1 per 1000 before the marrow nailing operation increased to 60 per 1000 within a few weeks without any liver therapy. The red blood count was also improved. In a certain number of cases SLANY observed a drop of the number of erythrocytes. He sums up his experiences as follows:

1. The hemopoietic system responds to the marrow nailing operation by a considerably increased release of reticulocytes which lasts as long as the nail remains in the marrow cavity.

2. The high reticulocyte values return to normal within a very short time after removal of the nail.

3. The larger the size of the fractured long bone and the younger the patient, the more pronounced is the release of myelogenic leukocytes to the blood circulation (myelocytes and transitional forms). In juvenile persons they may reappear repeatedly even after the first few days following the operation.

4. The bone fracture in itself also initiates a short lasting release of transitional forms of the white blood corpuscles as well as a pronounced increase of the reticulocytes in the blood.

5. The eosinophilia after marrow nailing operations in children which has been observed by this author occurs to a varying extent in adults as well. It disappears the same as in children, promptly after the removal of the nail.

6. A considerable number of patients respond to marrow nailing with a transitory, more or less pronounced decrease in the number of the red blood corpuscles and of the hemoglobin content, sometimes to a critical degree. This anemia spontaneously subsides even with the nail in the bone.

7. An increase in the number of the red blood corpuscles and of the hemoglobin values is observed in almost all patients after the removal of the nail.

It is rather striking that more than 50 % of the nails removed by SLANY revealed very fine marks of corrosion. The reason for this high percentage is difficult to explain. The possible reasons were discussed in chapter II. Such shortcomings caused by the metal can most certainly be eliminated in the course of time by an improvement of the alloy of the nails and by a proper treatment of the material. A careful handling of the nails is also essential to avoid scratching the polish. Sometimes one may observe that the complete assortment of the marrow nails is handled like a box of scrap iron. There is no doubt that boiling the marrow nails in direct contact with other metals is detrimental to the polish. In many clinics the instruments are sterilized in tap water. This involves the hazard of a damage to the polish of the nails by S, SO4, NO2 and NO3 ions.

The described changes of the blood and local injuries due to rust can probably be eliminated by the use of pure V2A-steel or the American Vitallium alloy which is free from iron. Experiences with Vitallium nails have not come to my knowledge. For the present it can safely be said that the relative frequency as well as the extent of the described injuries do not urge the use of new alloys.

SCHUETTEMEYER has examined the blood count as well as the sternal punctate of the patient material of the clinic at Kiel and his findings do not corroborate those

of SLANY. He did not find a change in the number of reticulocytes nor any other disturbance of the blood count.His cases did not,however, reveal any lesions due to rust, since pure V2A-steel had been used throughout.

At the suggestion of GUETTNER, E. MAYER has examined the sedimentation rate of the red blood corpuscles in 60 cases before and after marrow nailing and during the whole healing process. An increased blood sedimentation rate was regularly observed after the operation which, however, did not exceed the values found with other methods of treatment of bone fractures. Normal conditions were usually restored one week after the operation. A slight increase was observed upon removal of the nails. These observations fully coincide with those made by KUENTSCHER.

After marrow nailing a slight febrile reaction was observed in completely aseptic cases. BOEHLER observed temperatures of 37.5 to 38°C. and mentions that such increases of temperature frequently occur even without marrow nailing. The temperature is normal again after a few days. KUENTSCHER almost regularly observed an increase in temperature in the nailing of fistulating fractures and pseudarthroses and after the nailing of gunshot fractures which were a few days old. This increase of temperature was normally observed one day after the operation, in some instances after 2 to 5 days. The increase of temperature sets in quite suddenly and at first appears extremely critical. The general condition of the patients is good and the temperature shows a lytic decrease to normal after a few days. An infection of the wounds or other septic symptoms are not observed. The temperature increase must therefore be explained with the resorption of wound decomposition products in the marrow cavity. The typical case of a patient, 26, suffering from an infected thigh fracture will be demonstrated below. (See Illustration 36).

Temperature chart.

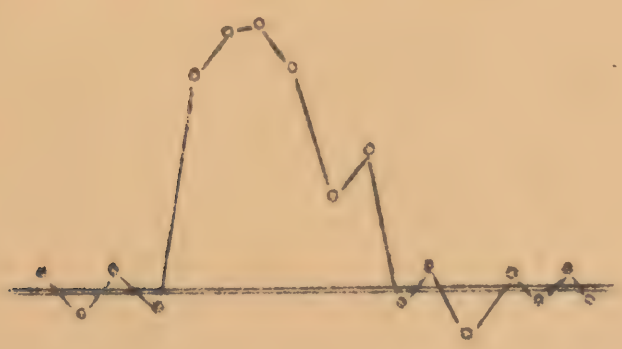


Illustration 36.
Typical pyrexia in a case of infected fracture. Considerable increase of temperature with decrease to normal by lysis.

Local Injuries due to the Metal of the Nail.

Other general disturbances than those described above have not become known. Local damage due to rust occurs sporadically. It may be said beforehand that the lesions are insignificant and they disappear of their own upon removal of the nail.

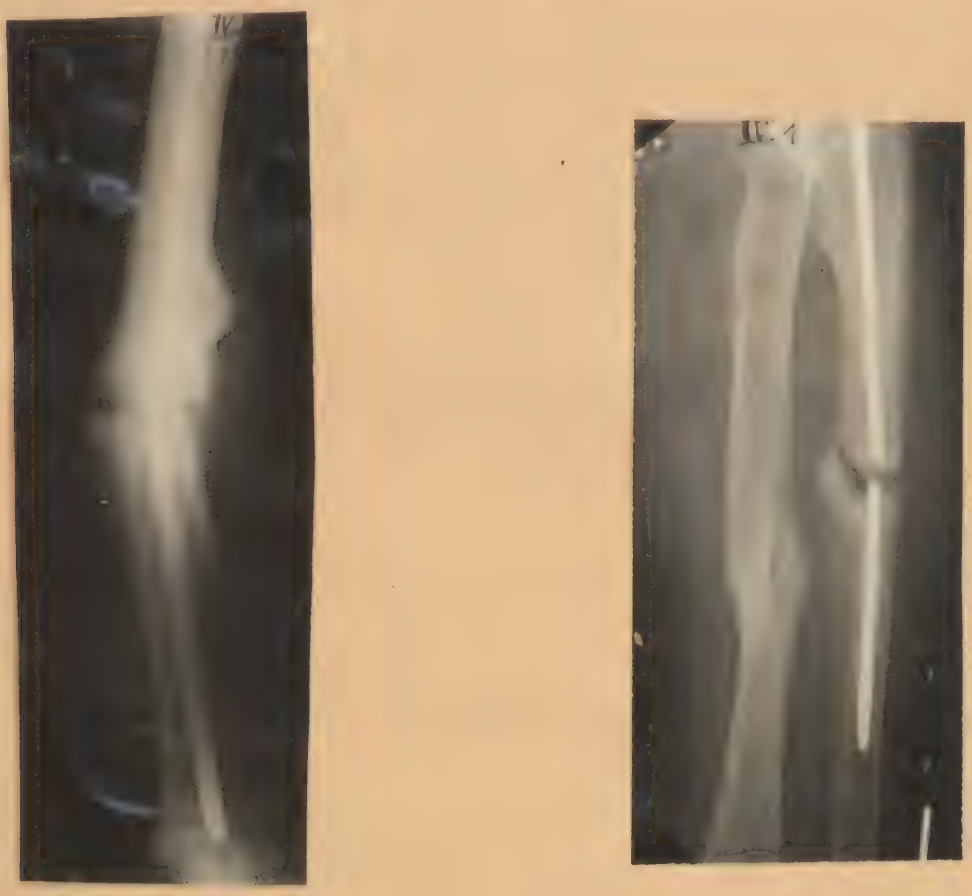
The metal used in the manufacture of marrow nails must have a high mechanical strength, since the nails have to withstand very strong forces. The metals must furthermore be resistant against the tissue fluid. Nickel chromium steel of sustenitic grain, as for instance KRUPP V2A-steel with 18% of chromium and 8 % of nickel and high grade alloys, such as Remanit steel, are suitable. So far, marrow nails were exclusively made of one of these alloys. The martensitic nickel-chromium steel grades with a low nickel content are unsuitable, because they are too readily deteriorated by rusting. Chrome plated steel nails are absolutely unsuitable. Experiences in the marrow nailing of the neck of the femur revealed that chrome plated nails rust very quickly. Through microscopic fissures of the chrome plating which may be caused when hammering on the head of the nail the salt solutions of the body gain access to the iron core of the nail. The presence of chromium-sodium chloride solution and iron constitutes a galvanic battery and the corrosion of the metals proceeds very fast. The austenitic steel grades are not absolutely safe against rust either, the oxide coating of these grades is, however, extremely thin and affords protection against a further deterioration. If this oxide coating is affected by permanent friction, the deterioration by rust will spread quickly. In case of the use of a double nail, deteriorations by rust will always make their appearance at those spots where the nails come in contact, even if both nails are made of the same metal or even made out of the same piece of metal. Strong formation of rust is also caused by a poor finish of the nail or if the nails were scratched by careless handling. The process of oxidation causes the surface of the nail to become rough and thus it happens that the deterioration proceeds. It is, however, curious that the head of the nail is never affected by rust, but only the shaft and the point, although the surface of the head always suffers when the nail is driven in. In an advanced state of deterioration the nail looks as though it had been gnawed and the destruction may reach such an extent that the nail cannot resist the stress any longer and will break.

Breaking of the Nails.

The nail is particularly liable to break if too thin a nail was chosen.

The mishap of a broken nail causes severe pain to the patient and is clinically easily recognized. A dislocation takes place not infrequently, which is, however, slight, since the breaking occurs only after the nail has

been in position for quite a long time. Callus has been formed in the meantime. As a rule only a dislocation of the bone ad axin occurs. The nail must be removed as soon as possible and this offers in most cases no difficulties. (See chapter V). The introduction of a new nail is easily performed since the old bed is used again, only the angulation must be realigned.



a b

Illustration 37.
Example of broken nails due to the influence of rust.

Bending of the Marrow Nail.

A bending of the marrow nail is not due to rust but to a sudden abnormal stress particularly by a new trauma. This occurrence is very rare. In KUENTSCHER's practice it happened once after the nailing of a femur fracture, incidentally the first osteotomy in which a marrow nail was used. The nails were made at that time of thin sheet metal and this incident gave rise to the adoption of the thicker sheet metal as is now in use, and no accident of this kind has happened since in the nailing of the femur. The case in question concerned a stout young man on whom osteotomy had to be performed because of an old femur fracture. The first attempt to compensate a shortening of 5½ cm. was successful. The patient was allowed to be ambulatory two weeks after the operation and was dis-

charged from the hospital after two more weeks. He rode his bicycle 18 km. (about 11 miles) daily without any trouble. Two weeks later the patient came back to the hospital with a bowed position of the nailed femur. It came out that he had jumped from considerable height into a sand pit and he immediately realized that he had bent the marrow nail. Contrary to all expectations the nail could be removed without any difficulty by approach from the trochanter major and without opening the fracture. Two assistants straightened the leg to the extent to which the nail gave way. In other words the nail was straightened by traction in the marrow canal. It could be easily replaced by a new nail and four weeks later the patient was able to resume his daily bicycle rides. The femur healed in a perfectly straight position, so that the incident had no serious consequences. The following unfavorable factors must have coincided in this accident:

1. There was a great dynamic stress due to jumping from a considerable height (the exact height could not be determined).

2. The impact did not take place on hard ground in which case it would have acted in a purely longitudinal direction to which the nail would probably have successfully resisted. The sand, however, gave way in a lateral direction so that a marked bending effect at the fracture site resulted.

3. By the fact that the thigh had been for many years in a bowed position, which had been eliminated all of a sudden, a persistent shifting of the muscle equilibrium in favor of the abductors was still effective.

The preponderance of the abductors was so strong that it could only be overcome in the operation with the greatest difficulty. Neither LANE's plate nor plaster of Paris could have counteracted the bending force of the group of abductors. Only the marrow nail can achieve this task and in this isolated case it failed because of the very unfavorable circumstances.

This case should not discourage us, as the definite shape of the marrow nail for thigh fractures had not yet been developed at that time. Patients with nailed femur fractures can without hesitation be allowed to indulge in sports. Only in case of osteotomies where considerable shortenings have to be compensated, abnormal stress should be avoided in the first weeks following the operation (see illustration 38).

a b c

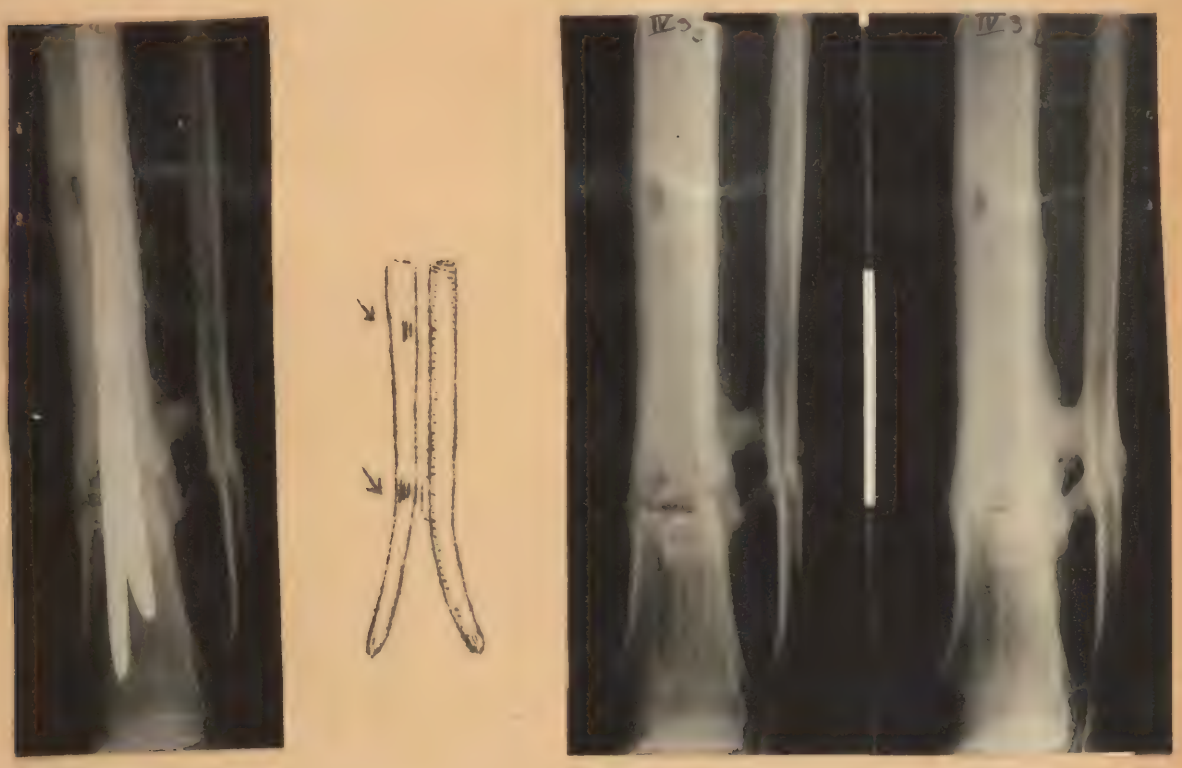
Illustration 38.
Example of a nail bent by jumping from a considerable height six weeks after compensation of a shortening of 5½ cms by osteotomy.
a) before the marrow nailing osteotomy
b) immediately after the nailing
c) after bending as a result of a jump into a sand pit.

d e

d) after replacement of the bent nail
e) upon removal of the second nail.

KUENTSCHER saw one more case of a bent marrow nail 15 days after the marrow nailing operation of a fresh simple fracture of the upper arm. The patient suffered a new trauma of the same arm as the result of a fall in the street. In this case the attempt to straighten the nail by reducing the arm under anaesthesia was successful, so that the incident had no persistent sequelae.

The oxidation of the nail leads to an intense irritation of the adjacent bone substance by rust which initiates a strong local callus formation which corresponds in location to the rusty spots as has been demonstrated in the experiment "callus formation without bone fracture". In some instances this results even in a circumscribed local destruction of the substance of the bone. These disturbances however, disappear without any further intervention few weeks after removal of the nail (see illustration 39).



a b c d

Illustration 39.

Damage due to rust in a leg fracture treated with a double nail (spread nail).
a) resorption spot in the bone and periosteal apposition which correspond in location to the rust spot.
b) appearance of the nail.
c) upon removal of the nail
d) after 6 weeks. The changes have been subjected to a considerable regress.

The clinical symptoms are pains in the respective spot which, according to BOEHLER, become greater especially at night. These pains disappear promptly upon removal of the nail. The same observations were made by SVEN JOHANSON in the extraction of rusty nails from the neck of the femur.

Damage due to rust was also observed by SPRENGELL, A. W. FISCHER, BOEHLER, RIEDER, STOEHR and others. Generally speaking it may be said that severe damage is a very rare occurrence. In case of double nails damage due to rust, though superficial, is the rule. KUENTSCHER observed in 104 of his own cases of femur fracture nailings only one case with damage due to rust. The damage was only superficial, although the nails were used several -three to four- times because they were difficult to obtain. On the other hand, SLANY reports that he observed rust in more than 50 % of his nails. It is difficult to explain the reason for this frequent appearance of rust.

This damage due to rust must be distinguished from the rarefactions which are sometimes observed around the point of the nail if it protrudes deep into the spongiosa. Attention was first directed to these rarefactions by HAEBLER. They develop if the point moves to and fro in case of a not yet fully stabilized osteosynthesis. This movement causes the rupture of numerous trabeculae of the spongiosa and the rarefaction is due to mechanical inflammatory processes of resorption which can be observed after every fracture. If the fracture is immobilized by an additional plaster cast, HAEBLER was able to observe reparative processes and a new margin of bone substance around the rarefaction zone. The same result can be observed when the callus at the fracture site has attained the necessary degree of stability so as to eliminate the movements of the point (see illustration 40).

Illustration 40.
Resorption zone around the point of the marrow nail due to destruction of the trabeculae of the spongiosa caused by wabbling of the nail.

Irritation effects due to insufficient fixation of the marrow nail in the marrow cavity may lead to a deposit of callus. These formations are likewise not due to the influence of the metal.

KUENTSCHER observed these formations several times after the resection of the femur (see chapter VI) if it had to attain such an extent that the entire median part of the bone was lost. The median part, however, constitutes the narrowest part of the marrow cavity and after its removal the nail is not firmly held in position so that the point of the nail may show slight movements in the distal part of the fracture. A medullar callus develops under these conditions which appears in the X-ray picture as an arc (see illustration 41).

Because of the shortage of material during the war, other nonoxidizing steels had to be used for the manufacture of marrow nails in addition to V2A-steel and this is probably the reason for the injuries described as due to rust. Pure V2A-steel, according to BOEHLER, is absolutely rustproof in the body, so that the hazard of the marrow nail in this respect can be fully eliminated. This fact is confirmed by HAEBLER.

SVEN JOHANSSON has devoted much of his time to the study of metal alloys for bone surgery and he found an alloy composed of 15 % chromium, 60 % of nickel and 16 % cobalt most suitable. In America, Vitallium is used in addition to chemically pure tantalum in the manufacture of bone screws and plates. Vitallium seems to be suitable, since it contains no iron and is, therefore, free from rust, whereas

a

b

Illustration 41.
Endosteal formation of medullar callus after resection and osteotomy, caused by circular movements of the point of the nail.
a) with nail in place
b) nail removed.

tantallum is too soft. As had been said before, there is no urgent need to abandon the austenitic nickel-chromium steel, damage due to rust being a rare occurrence. The surgeon is, on the contrary, always surprised to see when removing the nail, how perfectly it adapts itself to the tissue and how closely the connective tissue and the bone tissue grow around the metal of the nail. The metal may be said to "heal in".

If the nail was driven in too deep, so that its head stands out only a few millimeters, the

bone will grow over it and the nail is then difficult to locate. If a femur nail juts out by more than 1 to 2 cms. a bursa will develop around the head. This is not due to the metal but to the movements. The more the nail juts out, the greater will be the bursa. BOEHLER in some instances found "rice bodies" in it.

In some instances a bone hat was observed on the head of the nail. According to BOEHLER this hat takes the shape of a bone ring, if the nail protrudes by more than 5 cms. KUENTSCHER is of the opinion that the formation of this ring is initiated by medullar fat which extends along the groove of the nail (see chapter III). Contrary to that BOEHLER presumes that a certain disposition must be present in this case. It could also be possible that muscle substance was bruised at the head of the nail and that the formation of bone is engendered in these damaged muscle parts, comparable to the formation of bone at the cubitus in case of a myositis ossificans. Histologically it can be found that the ring consists of bone tissue interspersed with thick columns of connective tissue. BOEHLER also found striated muscle fibers and cartilage tissue.

The Hazard of Embolism.

The introduction of a foreign body of the size of a marrow nail necessarily includes the hazard of a fat embolism. We know from experience gathered in several thousands of nailings of the neck of the femur that here there is no such danger and the statistics of SVEN JOHANSSON, BOEHLER, and FELSENREICH do not include any case of fat embolism. The nail of the femur neck goes through a tissue which is composed of trabeculae of bone and bone marrow, while the marrow nail is inserted into pure medullar tissue, so that in this case the hazard appears greater.

The experiments of BUSCH have become known who injected oil into the marrow cavity by means of a cannula, after complete destruction of the marrow substance. Oil dripped out of the cannula for three hours. An overpressure in the marrow cavity was caused by a hemorrhage. In spite of numerous experiments it has not been determined so far, whether or not fat is aspirated from the marrow cavity by the veins without this overpressure. According to HOFHEINZ it is not likely that the aspiration of the veins plays an important role in the development of embolism. A suction effect of practical significance could only be attributed to the vessels which are situated relatively close to the heart; this does not apply to the vessels of the extremities. According to HOFHEINZ, fat embolism rather develops by forcing fat into open vessels. This opinion is shared by FLOURNOY, BERGEMANN and others. PELLIS succeeded in producing typical fat embolism by the introduction of laminaria rods into the marrow cavity, whereas this result could be attained only incompletely by destruction of the bone marrow. GROHÉ is likewise of

the opinion that an increase of pressure is necessary. No fat embolism will ensue if the fluid has other outlets. According to HOFHEINZ the fact that fat embolism is less frequent in fractures accompanied by injuries of the soft parts than in closed fractures seems to confirm this opinion.

At a cursory examination the marrow nail seems to act like the piston of a syringe pressing the contents of the marrow cavity into the region adjacent to the fracture site.

This is, however, by no means the case. The V-shaped marrow nail with its two lamellae fills only a small part of the cavity. In case of an osteotomy for instance where the nail is introduced into the wide open marrow cavity, the development of any overpressure is completely impossible. Consequently the contents cannot be forced into the vessels next to the osteotomy. But also in the case of the percutaneous nailing of the femur there is, generally speaking, no possibility for an overpressure to develop, since a sufficiently large space is left between the path of the guide rod and the nail to allow the fluid to drain out of the marrow cavity. As a matter of fact it is not infrequently observed that a few droplets of fat ooze out that way. If any apprehension in this respect would prove to be justified it would be easy enough to provide a bigger hole for the guide rod. In the nailing operations on the thigh and upper arm the guide path is made rather wide anyhow. As a matter of fact, the number of vessels damaged by the trauma is of primary importance with regard to the hazard of embolism. So, embolism is observed most often in comminuted fractures. These, however, are not suitable for marrow nailing. It is in this connection important to state that all patients with shock symptoms should be excluded from the marrow nailing operation. The operation should at least be postponed. The same applies to all fractures which show symptoms or are suspect of a fat embolism. The majority of the deaths from fat embolism due to accidents are accompanied by severe shocks and a concomitant collapse of the circulation,as the result of the destruction of tissues and loss of blood. We, therefore, have to do with a combination of deleterious factors.

MAATZ has gone into the matter in a limited series of tests on animals. He introduced marrow nails into both femurs and tibias of a dog and killed the animal. The histological examination of the lungs, kidneys and brain revealed a small number of fat droplets, as are seen after any bone fracture and to which no special clinical attention must be paid. Other experiments on animals carried through by MAATZ did not indicate an increased incidence of fat embolism.

BOEHLER reports that clinical symptoms of fat embolism are not observed as a rule and this statement is based on several thousands of marrow nailing operations. KUENTSCHER who paid special attention in this direction never observed distinct symptoms. Unfortunately there is

no method of determining the number of fat droplets lodging in the organs and the method of RUECKERT using a lipocrit to determine the total amount of fat circulating in the blood is of little use in this connection. KUENTSCHER experienced a fatal outcome of a marrow nailing osteotomy which he thought was due to fat embolism. It was the case of a young man, 26, who suffered from a supracondylar fracture of the thigh due to an accident. He had already been confined to bed for more than 6 months. Two attempts at an operative correction of the unfavorable position of the fracture had failed. The osteotomy was extremely laborious and caused a considerable loss of blood. In this case the worse came to the worst in that the nail became stuck, thus causing additional loss of time. The operation which was carried through under ether anesthesia took more than 2½ hours. The patient died a couple of hours later under the symptoms of a failure of the general circulation and shock. Post mortem findings revealed an anemia in all organs and a myocardiac deficiency. A fat embolism seemed to be probable. The later histologic examination did not reveal, however, the presence of an abnormal number of fat droplets in the organs, so that fat embolism, according to the opinion of the pathologists, could not be the only reason for the fatal outcome. As a matter of fact the patient was in a very unfavorable condition for this operation.

A. W. FISCHER and MAATZ have reported four fatal cases at the clinic in Kiel in which the post mortem findings histologically revealed fat droplets. Two cases refer to patients suffering from pertrochanteric fractures which were provided with Y-shaped nails. These two fractures were nailed under complete exposure at that time and this is a rather major operation (nowadays these nails are also inserted without exposure. See chapter V). The general condition was not too good in either of the two cases. Little fat was found in both cases and there were so considerable pathological changes of the organs that death had not to be considered as due to fat embolism but to shock, associated with the operation. One more femur fracture was nailed 7 days after the accident. Also in this case the histologically proved amount of fat was very low. The post mortem findings revealed a severe purulent bronchitis and pneumonia in addition to severe and extensive hemorrhages of the soft parts. In the case of the last patient there is a great likelihood that the displacement of fat had taken place prior to the operation. The patient fell from considerable height and broke both legs, he suffered from very severe shock symptoms when admitted to the clinic. The patient died four days after the marrow nailing. The post mortem findings revealed massive fat embolism in all organs. This is the only case of displacement of fat observed after nailing the leg.

HAEBLER describes in this connection 6 fatal cases among his patients after marrow nailing operations as follows: In two cases fat embolism can be definitely excluded:

1. Gunshot fracture of the femur. In this case amputation was necessary 23 days after the marrow nailing operation. Death caused by sepsis. Fat embolism could not be proven.

2. Leg fracture. Nailed 33 days after the accident with exposure of the site. Subfebrile temperatures were observed after the nailing. The operation wound healed primarily. The entrance wound of the nail had to be opened five days later. On the 11th day after the operation, following a blood transfusion the patient suffered from chills and fever and died from streptococcal sepsis originating from tonsillitis. Fat embolism could not be ascertained.

In a third fatal case there was little likelihood of death being due to fat embolism, since the fracture was nailed while the fracture site was exposed (see below). The patient was in a condition where any surgical intervention meant a serious hazard.

3. Femur fracture due to gunshot injury, 9 weeks old, with granulating, superficial wound of the soft parts. The general condition was reduced, the temperature was normal. As a satisfactory reduction by means of extension bandage could not be achieved, marrow nailing seemed indicated and this was performed with exposure of the site and removal of obstructing soft parts and provisional callus. The patient did not survive the anesthesia in spite of all possible measures including blood transfusion. Death occurred 4 hours after the operation and was caused by a general failure of the circulation. Post mortem findings: Flaccid heart muscle, moderate number of grey-red areas of infiltration in both lobes of the lungs. Microscopic findings are not available.

Contrary to the opinion of the pathologists, fat embolism must be admitted according to HAEBLER, as the direct cause of death in the following case:

4. Gunshot fracture of the femur in the proximal third with healed wounds. Good general condition. Attempt at marrow nailing 4 weeks after the injury. 1 cc. of S.E.E.(Scopolamine, Eucodal, Ephetonine) and other anesthesia. Introduction of the guide rod and nail into the central fracture piece without difficulty. Attempts at reposition of the fracture and introduction of the rod into the distal marrow cavity were unsuccessful. For this reason and because of the long duration and an increasing failure of the blood circulation the operation was interrupted and wire extension applied. Death occurred the same evening with symptoms of collapse. Post mortem findings: Cause of death cannot be clearly ascertained. The lungs revealed traces of fat embolism, which "under no circumstances can be considered as the cause of death."

The following observations seem to be particularly relevant with regard to the problem of fat embolism:

5. In the nailing of a femur fracture under lumbar anesthesia the guide rod was introduced after several unsuccessful attempts into the distal marrow cavity and the nail was driven in a few centimeters beyond the fracture cleft. On the attempt to remove the guide rod it was found to be jammed in the nail and it broke when force was used. The X-ray picture revealed that the nail was solidly engaged by the corticalis of the distal fragment, since it was introduced with its closed part next to the side toward which the proximal fragment was displaced. To maintain the good reduction of the fracture a second guide rod was introduced next to the nail in proper position. A short time after the second guide rod was driven in and while attempts were made to remove the first nail, the condition of the patient suddenly took a bad turn, the pulse rate increased to 160, the patient lost consciousness, respiration was jerky and the pulse was barely perceptible. When the attempt was made to remove the second guide rod it broke off too. Since the general condition of the patient became increasingly worse it was deemed advisable to cease operating and to saw off the nail on the following day. Upon administration of cardiac stimulants, oxygen and carbon dioxide the patient recovered slightly while in bed. Five hours after the operation the patient deceased, however, from a sudden heart failure. The post mortem examination revealed an air embolism in the right ventricle and a massive fat embolism in the pulmonary circulation with a complete obstruction of the arterioles and capillaries. The injection of a dyed solution into the femoral vein did not reveal a marked permeability of the blood veins towards the site of the nail. Extensive hemorrhages were found in the soft parts next to the fracture.

6. In a case of a femur fracture, 12 weeks old, which had already solidified to a certain extent with a lateral displacement amounting to the width of the shaft and with considerable shortening the fracture was mobilized under anesthesia and a wire extension was applied. By this measure the shortening was compensated except for 2 centimeters. The nailing operation was performed 7 days later (lumbar anesthesia and S.E.E.) The fracture could be extended but the lateral displacement of half the width of the shaft could not be compensated. The guide rod and the nail could be easily introduced as far as to the fracture cleft. In spite of using the nail as a lever and other measures the nail constantly slipped to the side of the distal fragment. These measures took considerable time and since the patient became nervous (which we think was due to the effect of Scopolamine) and the pulse rate and general condition became worse we even considered ex-

posing the fracture or interrupting the operation. As the condition improved, upon the administration of cardiac stimulants, the reposition apparatus was applied once more and an accurate reduction of the fracture was now achieved. The nailing was then performed without difficulties. The blood circulation, however, had considerably deteriorated and did not recover again, in spite of all measures applied. The patient died 4 hours after the operation. Post mortem findings: Massive fat embolism of both lungs. The fragments were closed by callus in which the nail was firmly engaged.

HAEBLER points out that displacement of fractures was only observed in femur fractures and that the incidence is relatively low as compared to the large number of nailings. He concludes that with the nailing of the femur pressure may occur in the marrow cavity under certain unfavorable conditions. If this pressure exceeds the pressure in the vein segments, that is the pressure necessary for the opening of the valves of the veins, medullar fat will enter into the blood vessels. The greater the number of open veins the quicker this process will occur. If other openings exist in the marrow cavity where little counterpressure is active, the marrow will use these outlets. The entrance opening of the nail and the fracture cleft constitute such openings. At the fracture cleft we have the pressure which is caused by the fracture hematoma tensing the soft parts.

In case of a nailing of the leg or of the upper arm a large hole is made by use of an awl which the marrow nail will fill only 1/3 at the most. The remaining 2/3 provide enough space for the marrow to escape when the nail is introduced. By contrast, in case of the femur, the nail and the guide rod will fill about 3/4 of the entrance opening, especially if a thick guide rod is used. The remaining space is apparently large enough to allow the marrow to escape and to serve together with the fracture cleft as an emergency outlet. It must be considered in this connection that the volume of the nail is very small.

If the fracture cleft is closed by callus as in old fractures, the emergency outlet which constitutes the entrance opening of the nail may be too small. This is especially true if the reduction maneuver is difficult and implies the opening of a great number of veins and extensive destruction of marrow. In case of old femur fractures it should therefore always be considered whether or not it is desirable to expose the fracture.

The hazard which arises from a hematoma under pressure at the fracture site with regard to fat embolism will be the greater, the earlier after the accident the fracture is nailed. If a wire extension is applied first, as was done for other reasons, the tension of the soft parts and with it the pressure of the hematoma will decrease.

This detailed description underlines the suggestion of KUENTSCHER. HAEBLER, with the view of avoiding the increase of pressure in the marrow cavity, suggests the

withdrawal of the guide rod repeatedly during its introduction to allow the marrow placed under pressure to escape. This procedure could possibly be combined with the suggestions of KUENTSCHER who proposes to enlarge the path of the guide rod before the nail is introduced. He uses an awl provided with a notch for the guide rod. (See illustration 42).

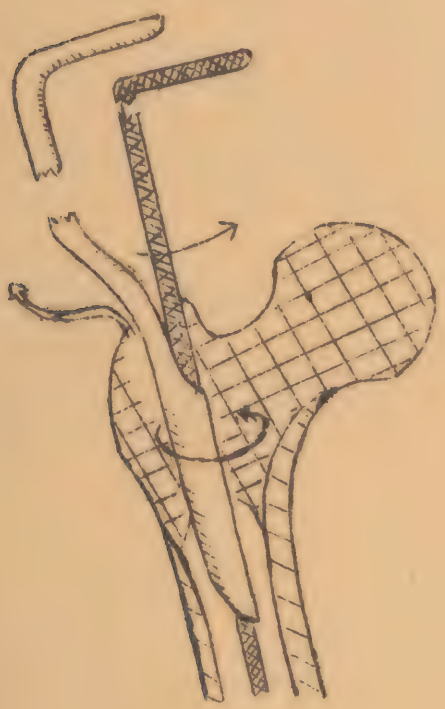


Illustration 42.
Awl with groove for the guide rod to enlarge the entrance opening of the nail in the marrow nailing of femur fractures.

The enlargement of the inlet facilitates at the same time the introduction of the nail, since the rod does not keep exactly to the center of the marrow cavity.

HAEBLER concluded his publications with the following words: "As compared with the overwhelming number of uneventful marrow nailing operations it may be said that the incidence of fat embolism is not more frequent than in other methods of treatment of femur fractures (with the possible exceptions of nailings with Y-shaped nails)." It is, therefore not justified to speak of an increased hazard of fat embolism in marrow nailing.

Among the cases where death was caused by fat embolism, there is not one instance in which the marrow nailing operation was performed under normal conditions, that is without complications. But rather in all these fatal cases incidents and complications occurred which prolonged the operation considerably. Here a severe operation shock developed as a result of ill-treatment of the tissues by unsuccessful attempts at reduction, jamming of the nail, forcible knocking about of the nail, breaking of the guide rods, kneading of the hematoma for many hours, etc. BOEHLER for instance describes a case in a hospital where the reduction could only be successfully performed after 4 hours of strenuous work. So, it may safely be said that shock plays an important if not the decisive role in the fatal cases. This is the more likely, since a certain displacement of fat is observed after each bone fracture and bone fracture operation. By preventing such a severe operation shock such fatal cases can be reduced in number or completely avoided.

Operation Shock.

It is the merit of BOEHLER to have emphatically pointed out the hazards of operation shock and to have given valuable suggestions concerning how to avoid it. Operation shock as a matter of fact constitutes the main hazard of the marrow nailing operation. The surgeon in the very comprehensible ambition to achieve a perfect reduction of the fracture will try everything and thereby unduly prolong the operation. If the nail is already in the bone the hazard of infection is increased by operating for hours. The legs and part of the abdomen being not infrequently freely suspended and covered only with thin clothes the body will cool down to a considerable extent. Added to this is the effect of the anesthetic and in case of osteotomies the loss of blood. BOEHLER found that the pulse rate is likely to rise to 160, if the operation and particularly the hammering on the bones is unduly prolonged and he advises to instantly interrupt the nailing operation, if the pulse does not return to 120 or less. BOEHLER pointedly says that one must never forget that one is hammering on a living individual and not on a piece of ironware.

It may justly be said that the shock and not the embolism, the infection, nor associated injury is the only and important hazard of the marrow nailing operation. And just this hazard can so easily be prevented by constantly thinking of it. The marrow nailing operation is one of the few operations which can be interrupted at any moment by closing the skin wound and applying an extension bandage. If the nail protrudes out of the bone it can be cut with a metal saw. If a metal saw is not available, or if it is indicated to interrupt the operation very quickly, the protruding section of the nail may be covered with a sterile bandage as suggested by BOEHLER. The following day a metal saw can certainly be obtained from a locksmith and it is early enough to cut the nail then. The rest of the nail can be easily removed if it gets loose after a couple of months.

A nailing is of course contraindicated if symptoms of shock due to the accident or associated injuries are already apparent as in the following case of the clinic of Kiel:

Victim of a railroad accident, man, 31, suffering from extensive injuries of the soft parts with torn musculature of the right leg from the knee down to the ankle bone. Broad excoriation of the skin of the left leg with several gaping flesh wounds and marked swelling of the joint of the foot. Complicated fracture of both tibias, fracture site about the middle of the tibia. Severe shock condition, slightly subsiding after blood transfusion. Both fractures were nailed under Evipan-Ether anesthesia. Patient died 6 hours later. Post mortem findings: Edema of the brain, dilatation of the heart, generalized anemia of the organs.

Hazards of Associated Injuries in the Marrow Nailing Operation.

From a purely theoretical aspect the hazard of an injury of nerves and vessels due to marrow nailing seems quite tangible. As a matter of fact it is quite possible that either the nail or the guide rod after penetrating the marrow canal of one piece of the fractured bone, might miss the canal of the other piece at the fracture site and pierce into the soft parts or even pass unnoticed alongside the bone. Such an incident has, however, never been observed in many thousands of marrow nailings performed so far. This is in the first place due to the particular shape of the point of the guide rod and nail which are rounded off as to permit the vessels and nerves to slide out of the way.

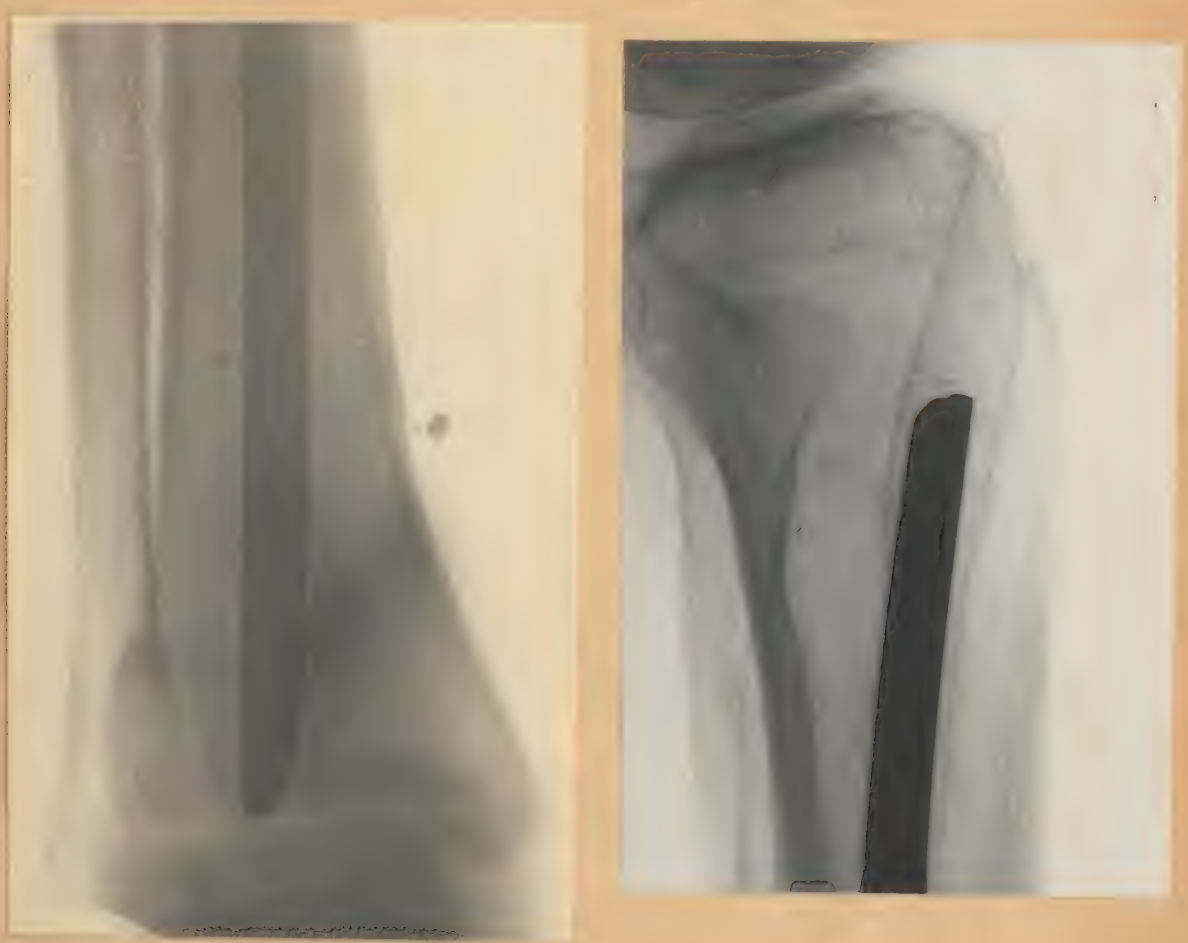
HART has observed 2 cases of nerve paralysis, involving the radial nerve in both cases. The injury was, however, not caused by the guide rod or the nail. In one case the reduction was extremely difficult and only succeeded after an angulation of the fracture. Four weeks later the exposure of the nerves revealed that the radialis was imbedded in callous scar tissue. In the other case the nerve was injured by a bone splinter that came off the humerus during the reduction. The paralysis subsided in both cases after neurolysis.

The hazard of splintering a bone is present particularly in oblique fractures, if the nail is too thick. This incident occurs very rarely as the nail will not enter any farther in spite of energetic hammering. A splintering is, however, likely to take place if the bone already has had a longitudinal fissure. Atrophic bone is particularly prone to this type of incident (see chapter V). In most cases the splintering is not complete. The osteosynthesis is, however, not stable enough and an additional plaster cast or extension bandage will as a rule become necessary. If the necessary care is taken, the splintering of the bone can be avoided.

The hazard of an injury of the joints is encountered if the nails used are too long or if the guide rod is driven in too deep. Both incidents can easily be avoided. (See chapter V). Such an injury to the joint will not have any consequences, if the position of the nail is detected early enough, unless the fracture is infected. It is, therefore, indispensable to have X-ray pictures made after each nailing operation and special attention must be paid to the joints as the incident may easily be overlooked in the elbow joint for instance. Such slight damages seem to heal without further trouble. In case of the knee joints the damage is usually insignificant because the nail passes through the condyles. Cases have become known where the nail was left for months in the knee joint and the full movement of the joint was restored, after the removal of the nail.

Wandering of the Nail.

Wandering of the nail could present a hazard to the joints. This is, however, only observed in very rare cases. KUENTSCHER was at first of the opinion that this could not happen with the ordinary marrow nail in contrast to the nail of the neck of the femur. In the meantime such wanderings have been described by A. W. FISCHER, RIEDER, BOEHLER and others. They are more frequent in old than in fresh fractures. FISCHER describes a case where the nail in the tibia had protruded from below the patella into the knee joint. After removal of the nail normal conditions were restored. KUENTSCHER had to treat a patient who had a fracture of the tibia which had been nailed in another hospital about 1 year before. The woman instead of coming back after 6 months as she had been told, for the removal of the nail, came when she suddenly felt severe pains in the ankle joint. Neither active nor passive movement was possible, although no effusion was detected and the swelling was only slight. The X-ray picture hardly revealed the old fracture site. The point of the marrow nail had entered the ankle joint. At the head of the tibia it could be seen that the nail had been in the ideal position. The path by which the nail had wandered could be followed by a distinct formation of bone margins. The head of the nail had retraced deep into the marrow cavity. (See Illustration 43).



a b

Illustration 43.
Wandering of the marrow nail in the tibia.
a) point of the nail had deeply entered the ankle joint,
b) the head of the nail has retraced deeply into the marrow cavity.

The removal of the nail was performed without difficulty by means of POHL's hook. It was found that three nails were introduced one after the other and the point of one of these nails had entered the ankle joint. After the removal of the nails the ankle joint was free from pain and the movement was almost entirely restored.

According to the observations of KUENTSCHER the nail will regularly wander out in case of fractures of the clavicle, unless it is secured according to the method of RAUTENWALD (see chapter V). The wandering of the tibia nails may also be prevented definitely by enlarging the head of the nail correspondingly. The firm of ERIKSON in Gottenborg for instance has developed tibia nails with heads shaped like a myrtle leaf sound. (See illustration 44).

Illustration 44.
Enlargement of the head of a tibia nail like a myrtle leaf sound to prevent wandering.

The wandering of the marrow nail in thigh fractures is rarely observed and exclusively in cases of pseudarthroses when too thin a nail was used. Here the nail usually wanders in an upward direction. This hazard could certainly be avoided by giving the nail an appropriate shape. These cases however, are so very rare that it is not worthwhile to develop a special nail. It is recommended to use sufficiently thick nails and in conformity with the suggestions of BOEHLER sufficiently long ones, the point of which reaches into the spongiosa of the condyles. In nailings of the forearm a wandering of the nail into the wrist joint is possible if the head of the nail was not bent outwards properly (see chapter V). In the radius the nail may wander into the joint by way of the head (see illustration 45).

Illustration 45.
Protrusion of the point of the nail of the radius into the elbow joint. No permanent damage to the joint after removal of the nail.

Pseudo Wandering of the Nail.

E. GUENTZ had performed a supracondylar osteotomy by means of marrow nailing on an 8 year old boy to compensate knock-knees. Since the knee joint was stiff, the marrow nail could be driven through the joint, so that a completely stable osteosynthesis was obtained. The nail was 55 cm long and was very firmly fixed because of its length. It extended beyond the point of the trochanter by 2 to 3 cm. After one year the X-ray picture revealed that the head of the nail had disappeared deep into the marrow cavity and the nail was located 2 to 3 cm below the tip of the trochanter. The head of the nail had formed a kind of a bony sheath which had grown larger to keep in contact with the receding nail. Thus a horn of bony substance was found on the point of the trochanter marking the way of the nail. This was not a case of wandering of the very long nail, on the contrary, the nail held in position firmly by the knee joint, but the femur had become longer by rapid growth (see illustration 46).

Damage to the Zone of Growth.

The marrow nail passes here through three zones of growth of the bone. The case illustrates that the growth of the bone is not hampered by the nail. Neither an acceleration nor a retardation was apparent. The growth was exactly the same as in the other limb. This fact could be established in all marrow nailing operations on children.

This case is a warning not to leave the nail in position too long in children. The removal can take place much earlier in children anyhow, since the fractures heal much more rapidly. In special cases and in the prophylactic marrow nailing of osteogenesis imperfecta in which case the nails have to remain inserted for a very long time, a frequent control, and if necessary, change of the nail will be necessary (see chapter VI).

a

b

Illustration 46.
Pseudo wandering of a femur nail in an 8 year old boy, which was in reality due to rapid growth of the femur. A sheath has formed on the nail indicating the path of the nail.
a) before the marrow nailing, the head of the nail exceeds the tip of the trochanter.
b) after 1 year it is found below the point of the trochanter (according to GUENTZ).

Hazard of Infection in Marrow Nailing.

In the era of penicillin and other effective antibiotics the following description doubtlessly is not up to date and it is rather of historical interest to see what progress was made in the field of the elimination of the infection hazard in the operative treatment of bone fractures. Nevertheless, this field shall be discussed in detail, if only for the sake of making the book complete. The topic is of scientific interest and is perhaps even of practical value, since penicillin is not available everywhere in sufficient quantities and as not every type of infection after operation could be prevented by its administration (see chapter VII).

The particular danger in the operative treatment of bone fractures is the danger of infection of the fracture cleft. Up to now this infection anulled, in a great number of cases, the good result of the reduction, or it at least affected the secondary healing because of the long lasting shift of the ion equilibrium of the tissue to the acid side (see chapter VI).

According to SVEN JOHANNSSON this hazard can be nearly disregarded in the extraarticular marrow nailing of the neck of the femur. This is still more true in the ordinary nailings that these two procedures should not be included in the so called operative treatment of bone fractures, as the fracture cleft is not opened and the conditions remain unchanged. The periosteum remains untouched and the fracture hematoma is not drained away.

The operation wound in the nailing of the neck of the femur is always 6 to 8 cms. away from the site of the fracture. An infection of the fracture cleft could, therefore, only be caused by the drilling wire or by the nail. Even though these were loaded with germs an infection could not quite easily be engendered since these would be brushed off at the entrance into the bone. The oligodynamic effect of the marrow nail metal seems to prevent a creeping of an infection from the wound to the site of the fracture along the nail. In 163 marrow nailing operations of the neck of the femur at the clinic at Kiel, 9 purulent infections of the wound were observed according to the investigations of KUENTSCHER. These infections healed quickly and did not penetrate to the fracture cleft. There was only one exception, in other words the hazard of an infection is less than 1 %. This particular infection was not fatal. Other statistics show similar results. The operative treatment of other types of fractures reveals entirely different figures, which vary between 3 and 30 % with a corresponding number of fatal cases, according to the type of the fracture. This makes the decisive progress clear which lies in the introduction of the extraarticular nailing by SVEN JOHANSSON.

In the ordinary marrow nailing the conditions are still more favorable.

1. The nail is introduced through a stab incision. This means that there is no operation area with a large wound, severance of muscles, ligature of vessels, numerous buried stitches, etc.

2. The distance between the entrance spot of the nail and the fracture site is always considerably larger than in the nailing of the neck of the femur.

It is not sure whether the bactericidal property of the marrow plays a role or not in this respect. This is very probable but would have to be proved by experiments.

ERB was in a position to prove the pronounced bactericidal property of the bone marrow. Very recently F. BORDASCH has published the result of his experiments on rabbits. He was able to prove that the hematoma of the marrow has no influence on the bactericidal property of the bone but that on the other hand blunt trauma of a long bone produces a long lasting increase of these properties. In the so called regeneration stage after considerable losses of blood, the bactericidal power increases still more, about 20 times. This increase can be proved even within a few hours. There is no doubt that similar processes will develop in the regeneration of the marrow cavity which will cause a similar increase.

The extraordinary susceptibility of osteotomies and of complicated fractures to the infection hazard probably does not lie in the fact that the marrow cavity is opened, but rather in the fact that numerous bone necroses are present which are due to the detachment of the periosteum etc. and which creates a condition favorable to the invasion of bacteria.

In the infection following a closed marrow nailing, one must strictly distinguish between infection of the entrance incision of the nail and infection of the fracture site. The former is a harmless event without any consequences, since we do not have to do with an operation involving the exposure of large areas of tissue etc. According to the statistics of REICH, GRIESSMANN and SCHUETTEMEYER of the clinic at Kiel 12 out of 341 closed marrow nailing operations were accompanied by an infection. That is a percentage of 3.5. BOEHLER observed 5 purulent infections of the entrance wound in 168 marrow nailing operations, that is 2.9 %. HAEBLER observed 3 infections in 140 operations, that is 2.1 %.

For comparison it may be noted that the infection rate after operation of inguinal hernia according to TEICHERT amounts to 2.3 %, according to KIRSCHNER to 5 % and according to GROGON to 6.8 %.

The suppuration of the entrance wound subsides after a few days if the suture is removed in due time. The infection will, as a rule, not follow the path of the nail, so that the infection of the fracture cleft must not be feared. If the wound is not opened in time, the infection may, of course, spread. Special care is

necessary in these cases and the patient should as a rule not be allowed to be ambulatory as long as the wound is inflamed.

What is the present incidence of an infection of the fracture cleft in the closed marrow nailing operations? The statistics of the Kiel clinic set forth the following figures:

Bone Infections and Generalized Infections after Marrow Nailing of Closed Fractures.

Total number of cases		Number of infections	
Clinic at Kiel	340	5	
BOEHLER	168	1	(not nailed by BOEHLER)
HAEBLER	140	1	
EHRLICH	40	1	
RIEDER and SCHUMANN	40	-	
HERZOG	12	-	
GRAND TOTAL:	740	8	= 1.1 %

As HAEBLER points out, such infections are most likely to happen if the reduction of the fracture presents considerable difficulties. There are many hazards of breaking asepsis if the operation lasts for several hours. BOEHLER shares his opinion. HAEBLER thinks that an infection can well be avoided if strictest asepsis is observed throughout the whole operation.

With an increasing experience and perfection of the technique the infection rate will certainly drop. One could for instance think of a nail that could be introduced in complete asepsis, in that it will not come into contact with the air or with the skin of the patient or other objects. This could be achieved by encapsulating the guide rod as well as the nail in sterile metal cylinders. The nail will then be driven in by pushing on a piston sliding in this cylinder. This possibility is of limited use, however, since the infection rate is relatively low.

As a matter of fact, a certain number of infections occur also in the conservative methods of bone fracture treatment. They are due to decubitus developing in the plaster cast, gangrene caused by an overtight plaster bandage, and to infection of the clamp-, nail-, or wire extension wound. HOELSCHER has observed for instance inflammatory processes in 25 % of his nail extensions and in many cases fistulae developed which lasted 8 to 9 years. HESS reported in 1924/26 about 60 cases which were treated with the STEINMANN pin and which included 16 infections = 26.7 %. KRABBEL reported on a purulence of the hip joint caused by a wire extension. According

to a survey of BOEHLER the following fatalities occurred in the conservative treatment.

In 40 nail extensions SCHEFFLER observed a development of fistulae 6 times with 1 fatal case. SCHWARZ: 1 fatal case out of 18. KOERNER: 1 fatal case out of 70. BOEHLER himself has seen neither an infection nor a fatal outcome.

KUENTSCHER had no infections of the fracture cleft and no fatal cases in his closed marrow nailings. The same is true for BOEHLER, HAEBLER, EHRLICH, RILDER and HERZOG. The clinic at Kiel recorded one fatal case due to infection, which GRIESSMANN and SCHUETTEMEYER describe as follows:

The nailing operation was performed on a patient, 54, suffering from a simple fracture of the femur. The operation was uneventful. The fracture was located in the lower third, a stable osteosynthesis was not achieved and the thigh was therefore supported on a BRAUN's splint. Due to air raid precautions the patient had to be transferred to an auxiliary hospital about 80 km. away. Ten days later an erysipelas developed at the entrance wound of the nail which was widely opened. Only one month later could the patient be readmitted to the main hospital and several abscesses of the thigh were opened right away. The patient died a few days later. We are convinced that this would not have happened if the patient had been under close clinical observation.

A series of other fatalities was described in the literature. They are listed here according to a survey of H. REICH which sets forth all fatal cases due to a bone infection after the marrow nailing of closed fractures:

1. Closed transverse fracture of the thigh in a child, 5, which was nailed 10 days after the accident. The operation was followed by high fever. On the second day after the operation the child died with the symptoms of an acute osteomyelitis (KRENSLEHNER, cited by BOEHLER).

2. Closed fracture of the tibia in a man, 63, with a markedly developed hematoma at the fracture site. Marrow nailing one day after the accident. About three weeks later, following the infection of the entrance wound an abscess developed at the fracture site, which involved, some time later, the entire tibia and made an amputation necessary. The amputation was followed by pyemic metastasis of the right ankle joint and pleura empyema (EHALT). Fatal outcome after 5 months of illness.

3. Closed fracture of the left leg in a man, 23, in addition to severe compression fracture of the 12th thoracic vertebra, penetrating wound of the right knee joint, extensive hematoma in both thighs. Marrow nailing of the left tibia was performed six days after the accident when it seemed that the knee joint wound of the right leg would heal. The knee wound

became purulent and a serious pyemic condition developed accompanied by a metastatic infection of the hematoma of the tibia fracture of the left leg and an infection of the hematoma of the thigh. Amputation was performed. The final outcome was fatal. (Observation of the clinic at Kiel).

4. Simple thigh fracture in a man, 26, after marrow nailing severe infection of the entire marrow cavity with multiple abscesses of the lungs and kidneys. High amputation. Fatal outcome. The post mortem findings revealed: diffuse coma, purulent invasion in the whole bone marrow of the thigh and of the area of the trochanter up to the condyles of the femur. Most severe phlegmons of the bone marrow with total purulent decomposition of the marrow. No details concerning time of the marrow nailing operation etc. (Reported by RAISCH).

5. Closed comminuted fracture of the femur with infection of the fracture site, because the entrance opening of the nail was located in a large area of skin burned in the 3rd degree. Marrow nailing 24 hours after the accident when the skin was already infected. Abscess of the fracture site and ejection of a couple of sequestra. Bony healing in good position with shortening of 1 cm. The marrow nail greatly facilitated nursing of the extensive burned areas (BOEHLER).

6. BOEHLER was asked to give his expert opinion in the following case which was communicated by him: Closed thigh fracture. Marrow nailing three weeks after the accident which was achieved "after 4 hours of wrestling". Splinters broke out of the proximal and distal fracture pieces. The entrance opening of the nail became purulent and healed only after the removal of the nail. Healing in good position with a flexibility of the knee of 180 - 75 degrees. One year later the patient fell ill from a puerperal thrombophlebitis, fistula at the inner side of the femur and irritation effusion in the knee joint. The relation of this new sickness with the former infection of the entrance wound of the nail was considered as probable.

7. Closed fracture of the tibia in a woman, 45. Marrow nailing three days after the accident. Because of the marked hematoma and the nail not uniting the parts of the fracture accurately due to the wide diameter of the marrow canal, the fracture was splinted. After 3 weeks septic conditions developed from an infection at the entrance opening of the nail. The fracture site became purulent and subsequently an abscess at the ankle bone developed. The nail was removed after 4½ weeks. The treatment was continued with a plaster cast. The fracture healed in good axial position, free mobility of the joint, no shortening (Clinic at Kiel).

8. Child, 2, transverse fracture of the right femur in the middle of the shaft. Nailing on the 7th day after admission (1 August 1941), because despite several prior attempts the fracture remained in a lateral displacement with shortening. The marrow nail then stuck in the marrow cavity which was too narrow and could not be driven in as deep as was necessary; it protruded by more than 4 cm. over the trochanter major, a distance far too great for a small child. As the operation had already lasted too long a change of the nail was not considered. After 3 weeks a fistula developed at the entrance opening of the nail. The nail was removed after 5 weeks when a sufficient solidification could be expected. At the request of the parents the child was discharged from the hospital on September 8. - Fluctuating swellings were later observed in the area of the fracture site. The X-ray picture did not furnish any clues for sequestra. The fracture site was strongly bridged over by callus. Incision was performed. A considerable amount of pus came out. Fenestrated hip plastercast was applied. Another incision of an abscess was made on 22 November. The child was again discharged on 20 December with healed wounds. (Records of the Clinic at Kiel).

9. Patient, 22, suffering from a double fracture of the left femur, oblique fracture in the zone between the upper and middle third and transverse fracture between the middle and lower third. It was intended to test the new spread nail, but the plan was dropped as technical difficulties were too great. A nail was introduced according to the instruction of KUENTSCHER together with a wire extension through the condyles of the femur to prevent a shortening due to a longitudinal splintering of the third fragment. After 2 weeks there was an increase of temperature the cause of which could not be determined at first. After 5 weeks fistulation of the entrance opening of the nail occurred. Bacteriologic findings: Hemolytic staphylococci. After 12 weeks abscess at the fracture site. Repeated incisions. Fever subsided. The callus formation was good, nevertheless a valgus position and bending to the front developed. The position was then corrected, pelvic plaster cast was applied, which was cut down to a shell after three weeks. Patient was allowed to get up after 5 months. Removal of the nail after 6½ months. Final result: Fracture healed in good and correct axial position. Wounds closed. Hip and knee joint both limited by about 50 %. Discharged upon his own request. Total time of treatment 6½ months. (Records of the Clinic at Kiel).

10. Patient, 52, with simple transverse fracture in the middle of the left leg. Attempt to use a new shape of nail (turn-spread nail developed by MAATZ). The posterior nail stuck however and had to be cut off at the entrance opening. This caused a separation of the fragments by 2 cms. The nails were removed after 3 weeks and the use of a double nail separated the fragments again, so that an ordinary nail is

finally used. 3½ weeks later infection of the entrance opening of the nail and abscess at the fracture site. Incisions. Bacteriologic findings: Hemolytic streptococci. A plaster shell is applied to the entire leg. After 15 days the abscess at the fracture site has healed. In the further course a pseudarthrosis of the tibia develops. Resection of the fibula. Removal of the nail after 5 months. Ambulatory plaster cast. The fistula at the entrance opening of the nail is closed. Callus formation and position satisfactory. Free mobility of the knee. Discharged as healed (records of the Clinic at Kiel).

Case number 3 cannot be blamed on the method. The severe generalized infection originating from the primarily infected knee joint of the other side caused a metastatic infection of the fracture site. This case was therefore not taken up in the statistics as a fatal case due to marrow nailing.

In case number 6 a revival of the infection after 1 year was observed. This fact must not be interpreted as a typical feature of the marrow nailing. It came after an approach to an osteomyelitic process which healed. Those revivals of osteomyelitic foci are also observed in osteomyelitis of different genesis, for instance after an infected osteotomy with simple dissolution of the fragments.

H. REICH concludes from his calculation that the total mortality rate on the basis of the figures available at the end of 1943 in the marrow nailing of closed fractures amount to 0.5 % (3 cases out of 593 marrow nailing operations).

It goes without saying that the total number of fatal cases is considerably higher as the greater part probably were not published. But likewise the total number of marrow nailings is considerably higher, since the method was adopted in a very great number of large and small hospitals.

The infection rate and mortality in the formerly applied osteosynthesis with wire suture, LANE's plates, etc., is considerably higher and in many reports and publications the hazards were emphasized again and again. W. BLOCK for instance writes: If one considers the fact that mishaps are only reluctantly communicated and only by very capable surgeons, the real number of postoperative infections after osteosynthesis must be far higher. Up to 30 % mortality has occurred in the treatment of simple femur fractures even in hospitals under the direction of capable surgeons. This also explains the fact that the Health Insurance Companies were against the operative treatment (CORNIOLY, KOENIG).

DAHL IVERSON, Coponhagen, found in 274 control examinations of osteosyntheses that an ostitis had developed in 35 % of the cases, pseudarthroses in 7 %. LEVANDER, Stockholm, had 3 infections in 22 of his own cases, which led in one case to amputation. Among 32 cases collected 6 cases of infection were observed.

BOEHLER reports about 5 femur fractures which he had to examine in the course of 6 weeks. In 3 cases infections had developed after the operative treatment of the fracture including the elimination of large sequestra and fistulae which lasted 1 to 2 years. A relatively favorable statistic was drawn up by V. HEDEY. He reports about 120 operated fractures of which 93 healed aseptically and in 27 cases infections developed. 98 cases were healed, 20 cases improved and 2 cases were fatal.

When comparing these figures with closed marrow nailing osteosynthesis, outstanding importance must be attached to the marrow nailing as a means to fight the infection hazard after the osteosynthesis. The question arises whether the hazard can be accepted in the cases where an infection develops. This question refers in particular to the open marrow nailing (see chapter VI). In open marrow nailing and in the case of a pseudarthrosis since the fracture is exposed, the advantage of the low infection rate does not hold true, as it does in the case of closed marrow nailing. The nail here takes the place of a wire loop, clamp, etc. The rate of infections is also considerable when marrow nailing is done under these circumstances.

KUENTSCHER observed 10 infections in 38 cases of marrow nailed osteotomies after healed fractures and pseudarthroses due to gunshot injuries. That is 26 %. It must be borne in mind, however, that the infection rate is particularly high in gunshot or other war injuries due to the special damage to the tissue (see chapter VI and VII). KUENTSCHER observed 7 cases of infection among 67 cases of marrow nail osteotomies, that is 14 %. Still more urgent is the problem of the infection course after the marrow nailing of the complicated fractures or even the fresh gunshot fractures. In these cases a high number of infections must be anticipated. KUENTSCHER found a rate of infection amounting to 64 % after the marrow nailing of fresh gunshot fractures. For this reason there is a large amount of experience available on the course of infections after marrow nailing. A. V. FISCHER, R. MAATZ, and H. REICH have paid particular attention to this problem.

Symptoms and Course of Bone Infection in Marrow Nailing.

The infection of the entrance opening of the nail is purely an infection of the soft parts, which is of no particular significance. From the theoretical aspect the consequences of an infection in the marrow nailing should be disastrous in consideration of the size and the length of the foreign body involved. Experience has shown that this is usually not the case. As a rule not even a severe generalized osteomyelitis will set in. The bone inflammation following the marrow nailing occurs in two different types according to the classification of H. REICH.

1. Bone inflammation without participation of the marrow. This is an ostitis limited to the ends of the bones. The clinical course is mild.

2. Bone inflammation with participation of the marrow. A form of osteomyelitis, typical in marrow nailing. This is a severe disease with a subacute or even chronic course.

Pathologico-anatomically these are a demarcating inflammation in the bone marrow and an ostitis is limited to the fracture site, in the course of which typical annular sequestra may be formed under certain conditions.

The clinical course is no more severe or more dangerous than that of an osteomyelitis following the conservative treatment of complicated fractures. In case of the closed marrow nailing the germs are brought to the fracture site by the guide rod or by the nail or in case of an infection of the entrance wound of the nail they follow the path of the nail and come that way to the fracture site, if the wound is not opened in due time. In case of an osteotomy or a complicated fracture they pass directly into the fracture cleft.

The further course of the infection then depends on the one hand on the quantity and virulence of the bacteria and on the other hand on the resistance of the body. Furthermore it depends on the extent of the necroses (see chapter VI), on the possible drainage of the wound and finally on the stability of the osteosynthesis.

In the mild forms of ostitis without participation of the marrow a slight increase of the temperature and a moderate discharge of pus from the wounds will take place. The healing of the bone is hampered by the formation of small sequestra. According to the survey of H. REICH the final result of these cases differs in no way from those of a fully uneventful healing. The inflammatory decomposition of the bone does not appear more pronounced in the X-ray pictures than in other complicated fractures after a complicated treatment. The inflammation is limited to the fracture site. The annular sequestra are not observed. (H. REICH, EHALT, EHRLICH and CELLARIUS).

The following history of the patient O.M., 27, is given as an example. He suffered from a fracture of the tibia which had developed into a pseudarthrosis in an extension bandage. The marrow nailing operation was performed 9 months after the accident, the pseudarthrosis cleft was opened and fibula resection was performed. 3 days after the operation the patient showed 38°C. fever and redness of the wound appeared. Both, the wound and entrance site of the nail were opened immediately. A small amount of pus came out. In the following days the temperature increased at times to 38.4 degrees but soon returned to normal. The wound had a moderate purulent secretion for about 8 weeks, so that the patient could be allowed to be ambulatory only after 9 weeks. No elimination of sequestra was observed. The infection did not creep along the path of the nail. The pseudarthrosis

healed in a good position with formation of bony substance.

In case of a bone inflammation with involvement of the bone marrow, that is marrow nailing osteomyelitis, the infection spreads to the marrow canal and a demarcating inflammation of the marrow next to the nail develops. The correlation of the severity of this inflammation with the extent of the necrosis is quite apparent. According to REICH there exists a direct ratio between the extent of the injuries of the bone and soft parts and the severity of this infection and its sequelae. High fever is observed. This must, however, not be confused with the increases of temperature which generally occur after the marrow nailing operation and which are of no consequence. An infection in the closed and open marrow nailing can occur only after several weeks. These infections generally have a mild course. In some instances where the wound was not properly opened, the pus will force its way along the nail forming an abscess at the head of the nail. This abscess may in case of a femur nailing grow to the size of a hen's egg. The time for the progress along this path is about 6 to 8 weeks. The inflammation does not invade the whole marrow cavity at once but rather progresses gradually. This spreading takes place only if the drainage is materially hampered. If drainage of the inflammatory substances is not secured in time, the pus under high pressure will cause a total medullar phlegmon under severe septic conditions. This incidence, is, however, very rare. It is recommended to nail complicated and comminuted fractures under direct exposure to avoid the hazard of such severe infections (see chapter VII).

As a matter of course the stability of the osteosynthesis will play an important role in the spreading of such infections. If the fragments of the fracture are well united, the marrow nailing will guarantee an ideal position at rest. This will have a favorable effect on the course of the infection. The spread of the infection can also be favored directly by a loose marrow nail the motion of which will force the pus from one place to another.

In 105 cases of marrow nailed osteotomies without fistulae, KUENTSCHER saw one fatal outcome due to infection. The osteosynthesis was not stable in this case and this probably explains the regrettable result (see chapter VI).

This case refers to a patient, 24, who one year previously had suffered a fracture of the ankle joint due to a gunshot injury with loss of the talus and healing occurred in an equino-valgus position. A fistula did not exist at that time. The musculature and the foot were highly atrophic. A wedge osteotomy was performed close above the ankle. The nail was driven in from the sole. (See chapter VIII). The osteosynthesis was not stable because an ordinary short femur marrow nail had been used which had little hold due to the absence of the talus. This type of nailing cannot be considered as a marrow nailing properly speaking, since the nail lies

partly in the spongiosa. No fever was observed in the first week. Then a sudden fever up to 39.6°C. set in. Since little was to be seen at the foot and the patient did not complain about pains it was neglected to open the operation wound widely. Three days later an empyema of the knee joint developed. This was opened and the temperature dropped temporarily. Some days later high fever was observed again and under the symptoms of sepsis the patient deceased three weeks after the operation. The post mortem examination revealed a purulent phlegmon of the entire marrow cavity, empyema of the knee joint and numerous purulent metastases in the lungs, the myocardium and the musculature of the right upper arm. (See chapters VI and VIII.)

This tragic outcome could have been avoided by a timely wide opening of the wound and the strictest immobilization. The immediate wide opening of the fracture site or of the wound of the osteotomy is the most important measure if an infection sets in after the marrow nailing. The entrance opening of the nail must also be widely opened, since the nail has the effect of a drain tube draining the fracture from within. It is a serious mistake to remove the nail in case of an infection (see chapter V), since the immobilization of the fracture constitutes the most efficient factor in fighting the infection. For this reason, EHALT, PASCHE and others nail the febrile fracture patient. The nail is never the cause of the fever. In spite of these conditions many a case has become known where the nail was removed, whereas the abscess as the only cause of the fever remained undrained. A turn to the worse is the result of this mistake, because the drainage of the nail and the fixation of the fracture are lost. It must be admitted that the temptation to remove the nail is great in such cases where the fever does not decrease for weeks and where a profuse purulent drainage does not seem to subside. Nobody would, however, think of removing the drain tube from an infected, purulent joint with a severe suppuration.

If the osteosynthesis does not prove stable enough an additional fenestrated plaster cast is indicated. In all other cases this is not adviseable because it complicates the treatment and makes it more difficult to recognize tubular abscesses. If the entrance opening of the nail is suspected because of redness, pains, etc. it is always better to open the wound too often rather than not often enough. The wound will close in a very short time.

In most cases the infection will take a mild course after the opening of the wounds or adequate incision. In this connection the formation of ring shaped sequestra, which are typical of marrow nailing, is often observed if the pus secretion is very marked. (A.W. FISCHER, H. REICH). The sequestrum forms a ring in the middle of which lies the nail. This ring is entirely a part of the bone cross section. As a result of the reduction of the bone substance the outer diameter is diminished while the interior

one is enlarged. The length of the ring amounts to 1 - 2 cm. The distal and proximal limitation of the ring is jagged. The annular sequestrum usually occurs after the infection of an open marrow nailing if the periosteum was detached. This damage, however, may be caused by the suppuration. If this injury is associated with a damage of the endosteum due to the marrow nailing and infection, the decay of a whole piece of the bone fragments will ensue. H. REICH very justly compares this process with the occurrence of ring sequestra after amputations in which the periosteum at the outside and the marrow on the inside were curetted too high. The ring shaped sequestrum of the marrow nailing must thus be conceived as the sequel of a demarcating ostitis (A.W. FISCHER and H. REICH).

Since the periosteum is the principal element supplying the bone, the formation of sequestra generally affects the outer compact layers in a lesser degree than the inner ones. The outer layer of the compacta may even remain fully intact. This causes the outer shape to assume the form of a cone. According to REICH the inner shape may also be conical and the ends are not infrequently sharp as knife-blades. EHALT refers to this sequestrum as "conical sequestrum" whereas BOEHLER calls it "medullar sequestrum". The actual ring shape speaks, however, in favor of the term "annular sequestrum" as chosen by FISCHER and REICH. The expression of "medullar sequestrum" could give rise to different misunderstandings. These formations must in no case be confused with the formation of bony rings or tubes around the nail. These are due to the irritative effect of the nail and they are medullar callus. They consist of living bone (see illustration 47).

Illustration 47.
Typical annular sequestrum after marrow nailing of a pseudarthrosis of the lower arm. Strong formation of callus around the sequestrum.

The occurrence of ring shaped sequestra is by no means synonymus with the development of pseudarthrosis or shortening. The sequestrum is always imbedded into an abundant amount of callus. This causes a delay but not a hindrance of the healing process (see illustration 47).

The sequestra can always be easily removed. At best following the removal of the nail. They can be easily drawn out of the enlarged openings of the fistula at the site of the healed fracture. This type of sequestrum is rare. It is a matter of course, that the usual long pointed sequestra may also occur which owe their existence to the necrosis of detached bone splinters, which applies especially to the gunshot fractures.

Numerous examples for the clinical course of the marrow nailing ostitis and osteomyelitis with and without formation of sequestra are given together with the respective X-ray pictures in chapter VII. These examples concern the marrow nailing of open fractures and gunshot fractures which became infected and the nailing of already infected fractures. KUENTSCHER never observed the development of a pseudarthrosis in such cases. H. REICH makes the same statement. The regeneration process, that is the formation of new germinative bone tissue does not come to a standstill after the onset of the infection. The acid phase of the fracture healing (chapter III) is, however, considerably increased in duration because the shifting to the acid side was very intensive. This means deferred solidification (basic phase) and above all damages to the adjacent soft parts due to the hyperacidity and which are characteristic for secondary healing. Details are to be found in the beginning of Chapter VI. The regeneration processes are frequently intensified even with a considerable suppuration, as is also observed in osteomyelitis. The irritation caused by the infection, respectively by the foreign body, is considerably greater than that usually caused by the fracture. The irritation caused by foreign bodies and infections cannot be delimited from each other because the bone has only one possibility of reaction to such irritations (chapter III). We also observe an increased process of bone reduction (LANCHE). In spite of this the fracture will finally heal by purposeful formation of callus after the fixation of the bone ends by the marrow nail. (H. REICH). A callus luxurians is not observed in this healing process.

These statements are verified by the following histologic findings, cited in the paper of H. REICH. The findings were made on amputation or post mortem preparations.

1. Histological examination of a long inflammated bone which was amputated <u>3 weeks after the marrow nailing.</u>

After the removal of the soft tissue, the bone reveals in the very area of the fracture only a solid connective tissue, which is easy to cut. The fracture cleft is gaping. We have to deal with an oblique fracture. A thickening of the periosteum is observed

in a proximal and distal direction from the fracture site for the entire length of the bone, but particularly in the fracture area. The surface is of a grey-white color and rough in the fracture area.

The saw cuts do not reveal any exterior change of the bone. Fresh granulation tissue and pus is found in the bed of the nail in the fracture zone, that is in the center of the marrow. This zone includes half the marrow cavity, especially the center of it. Peripherally up to the inner margin of the compacta the marrow was modified into a grey-reddish soft tissue, apparently a granulation tissue. The ends of the bone are without apparent changes. At a distance of 5 to 7 cm. proximally and distally from the fracture site the bone does not reveal any exterior pathologic changes. The bed of the nail is clearly visible in the marrow as a V shaped path corresponding to the cross section of the nail. The same pus is found here, adjacent to the pus zone we find a small 1 to 2 mm zone of a more compact tissue and from there on in a peripheral direction a grey white loose tissue in which fat tissue zones are clearly visible.

The histological examination of the fracture site reveals that the space which was occupied by the nail is filled with a fibrinous substance with numerous pus corpuscles. Next to it lies a lamellary connective tissue surrounding or delimiting the nail bed. This connective tissue is strongly interspersed with fibrin and leukocytes. More towards the periphery fresh inflammatory granulation tissue is observed with numerous, newly formed blood containing vessels with a thin wall. In the meshes of the tissue we find a more or less pronounced edema. Further on in the direction of the corticalis towards the inner margin of the compacta there is a clearly visible but on the whole not strongly developed formation of medullar callus. This marrow callus is partly eroded and excavated by the activity of osteoclasts. In this area we also find remnants of the former marrow tissue in the shape of a reticular structure.

In the septa we find hyperemic vessels and also infiltrations with small cells. The fragments show erosion and jagging. The compacta in the fracture zone is very porous. Many dilated Haversian canals are to be found in which we distinguish sometimes edema and sometimes dilated vessels filled with blood. We also find polynuclear giant cells of the type of osteoclasts. The bone substance is irregularly stained which seems to point to a variable content of calcium.

A moderate formation of callus is observed in the region of the periosteum. This is recently formed callus. The bone corpuscles are still recognizable in the calcified basic substance as cystic

and thick cells. Furthermore we find young osteoid tissue with margins of osteoblasts.

At a distance of 5 to 7 cm. proximally from the fracture site pus and fibrin is demonstrable in the nailbed. The nailbed is here more distinctly demarcated from the connective tissue by lamellary connective tissue located in the circumference of the nail bed and in which we find here a considerably lower amount of inflammatory cells. Next to it extending to the inner compacta we find highly hyperemic bone marrow tissue. There are inflammatory cells in the septa. Furthermore a distinct formation of marrow callus with a more or less pronounced fibrosis of the marrow tissue can be observed in this zone. We have to do with recently formed or old marrow callus. Part of the newly formed callus is still in the osteoid state.

At the margin of the corticalis the marrow tissue is absolutely unchanged. The compacta is porous as a result of a lacunar disintegration.

The periosteum is thickened having the appearance of connective tissue. The fibrous columns show lamellary arrangement. A fresh formation of osteoid and definite callus with young bone cells and calcified basic substance is observed at the compacta surface of the periosteum.

In the distal area 4 to 5 cm. away from the fracture we observe on principle the same picture of alterations in the marrow, compacta and periosteum.

On the whole this case of suppuration of the bone continued over 3 weeks after marrow nailing of an open fracture as an inflammation of the bone marrow which was particularly severe in the fracture zone. It is worthy of note that the suppuration as such principally affects the tissue adjoining the marrow nail. It attains its highest degree in the bed of the nail. Although this nail bed is delimited by granulation tissue in the proper area of the fracture, the suppuration has spread over larger areas of the nail duct in the peripheral direction. In the proper fracture area the inflammation has involved the bone itself. Here it reveals noteworthy signs of destruction. It attracts attention that marrow callus is formed during the inflammation, consisting of fresh and old callus. The periosteal and regenerative processes did not come to a standstill either and there is fresh callus, even though its amount is not high.

A distinct decrease of the bone marrow inflammation can be noticed distally and proximally from the fracture site. At the ends of the nail the inflammation is very slight but still provable. As a conspicuous finding there is a distinct delimitation of the nail bed by connective tissue which is by far more pronounced here than in the proper fracture zone.

The resorptive processes in the bone are less intense. Finally we find zones of fresh regeneration in which medullar and periosteal callus is newly formed respectively in the process of formation. The inflammation of the bone marrow is quite obviously limited to the area next to the nail bed in this region more distant from the fracture site.

2. Histological examination of a femur which was amputated 9 weeks after marrow nailing. The case refers to a severe complicated supracondylar fracture in a woman, 51. (See also case 6).

The following preparations were examined:

1. Parts of the fracture site with bone marrow and nail bed,

2. the femur in cross sections above the fracture.

In the nail bed of the nailed fracture we observe fibrin and a small margin of nonspecific inflammatory granulation tissue which contrasts sharply to a wide and narrow meshwork of hyperemic medullar tissue with perivascular and microcellular infiltrations. In the reticulum, the cells of which have a large plasma and small intensively stained nuclei, we observe large fat storing histiocytes. Next to it we see a zone of freshly formed bone trabeculae with distinct zones of osteoblasts. Besides edemas the marrow tissue reveals a considerable hyperemia and relatively numerous diffusely distributed microcellular elements and also large histiocytes. The polynuclear elements are less important in number.

A narrow strip composed of blood and fibrin is seen in the cross section of the femur above the fracture site into which inflammatory cells are mixed. In these strips the marrow structure is lost. Next to it lies a sharply defined nonspecific inflammatory granulation tissue which gradually changes into loose granulation tissue. Finally we see a wide and a fine meshwork of marrow tissue (fat enclosures) with more or less diffuse perivascular microcellular infiltrations, small hemorrhages and strong hyperemia. In the zones which reveal a more pronounced organization and fibrosis we find a formation of marrow callus varying in degree. Fresh medullar callus is being formed, older callus recedes. The compacta zone and the periosteum show no signs of ostitis, or periostitis. A progress of the inflammation by way of the bone tubules cannot be observed. No abscesses are seen. The periosteum, however, shows the formation of periosteal callus formation which, although small, is recognizable in all cross sections and which is in most places in an osteoid state.

Concerning the proper fracture zone this case also reveals an inflammation which is, however, already considerably demarcated.

In some distance from the fracture site, the marrow tissue was seized by inflammation in the proper zone of the nail bed. But here too the bed of the nail is delimited to a great extent by connective tissue. It may thus be said that the inflammation did not invade all parts of the marrow. The compacta has remained unchanged in the areas remote from the fracture. A callus formation, though small, is distinctly observed in the marrow and periosteum in the form of fresh and old callus.

3. Histological examinations of the femur of a patient, 59, who suffered from a pertrochanteric femur fracture which was nailed with a so-called Y-shaped nail. A suppuration of the wound developed. The case was furthermore complicated by decubital ulcers over the sacrum. In the further course sepsis and a metastatic abscess above the right knee joint developed. In addition the suppuration spread to the right buttock. Death occurred 13 weeks after nailing with the Y-shaped nail.

The fracture area revealed an abundant amount of inflammatory edema, fibrin, and numerous pus cells. The inflammatory area is delimited by non-specific inflammatory granulation tissue which is the more thickened and fibrotic the greater the distance from the fracture site is. Dense scar tissue is thus formed in the environment of the fracture. No sign of regeneration is found in these areas. The bone of the neck of the femur and of the trochanter region reveals more or less pronounced resorption. Consequently dilated Haversian canals were found which were filled partly with edema and partly with hyperemic vessels. Microcellular infiltrations are to be seen in varying numbers.

A cross section of the femur 10 cm. below the trochanter reveals a strong hyperemia in the marrow and in addition the presence of edema. This finding is made in the immediate zone of the nail tract. The nail bed itself is delimited by compact fibrous columns. Dissimilation of marrow callus was also observed. The bone did not show any changes in this area apart from a slight lacunary resorption. The periosteum was without pathological findings.

The most distal areas of the femur, that is just above the condyles of the femur, reveal the same changes in the marrow, namely demarcation of the nail bed by connective tissue, hyperemia, edema and dissimilation of marrow callus. The resorptive signs are less apparent in the bone. No pathologic findings are seen in the periosteum.

The outstanding fact is, that in this case the bone inflammation was again limited to the fracture site. It started from a purulent operation wound. It thus became evident that the inflammation in the spongiosa of the bone was also demarcated by granulation tissue. A more pronounced porosity of the

bone next to the fracture site was due to the infection. The bone marrow of the femur itself was not invaded by inflammation. Pus cells were not observed. The nail bed is delimited by connective tissue. The bone marrow, although hyperemic and edematous, does not reveal any signs of inflammation or inflammatory exudate. The marrow callus is obviously receding. The bone reveals signs of dissimilation which decrease in intensity with the distance from the fracture site.

4. Histological examination of the tibia of a patient, 60, on which a secondary amputation due to bone infection was performed, 4½ months after the marrow nailing operation (see case 5).

Macroscopic findings of the bone preparation: After the removal of all soft parts the tibia did not reveal any apparent changes apart from the fracture which will be described in detail. The periosteum sheath envelopes the tibia and except at the fracture site it fits snugly to the bone without any detachment or abscess.

The fracture is simply bridged over by connective tissue. When cutting this tissue a grating of the knife was observed, indicating the presence of calcareous particles or bone remnants. The bone was then cut lengthwise in the middle by a saw and it could be observed that the condition of the compacta and spongiosa (ankle-region) apparently had remained normal above as well as below the fracture. The cut clearly showed that the compacta is followed towards the center, that is toward the marrow canal by a compact, 3 to 5 cm. thick lining of connective tissue. Above as well as below the fracture site there was soft marrow which in its center was purulent in the area where the marrow nail lay. The above described conditions were of equal appearance in all affected parts.

In the cross section a hole of about 2 mm. in diameter could be observed in the center of the marrow for the entire length of the bone. The bone marrow is missing at the ends next to the fracture site. Here are found intermediary enclosures of connective tissue. It could not be ascertained macroscopically, whether a formation of bony substance had already started or not. It is rather striking that the compacta as seen from the outside does not reveal any apparent changes. The area of the spongiosa of the ankle region did not reveal any changes either. Sequestra could not be detected. A formation of tender trabeculae is observed throughout. An abnormal porosity is observed nowhere.

The condition of the soft parts is of no interest in this connection and will, therefore, not be described.

Microscopic examination. Specimens were taken of the different areas of the fracture up to about 10 cm. above the fracture site. The specimens were prepared as described above.

Microscopic findings at the fracture site: The centrally located parts of the marrow were fully deprived of marrow tissue. Instead a tissue is found which is intermingled mainly with small cells and polynuclear inflammatory elements, besides masses of fibrin and sometimes enlarged thin walled vessels tightly filled with blood. These findings were made in the area immediately adjacent to the marrow nail. It is rather surprising that we find only a few inflammatory elements collected together into pus foci. This tissue which represents a granulation tissue with numerous inflammatory elements gradually changes into a normal granulation tissue the closer we come to the proper periphery of the marrow which contains a great number of obviously fat storing histiocytes.

This generally loose granulation goes lost in connective tissue of growing compactness in which the inflammatory elements take on the form of perivascular and predominantly microcellular infiltrations. The vessels have here a thick wall. The quantity of the inflammatory infiltration decreases distinctly. Here one sees the picture of the sheathing of the centrally inflamed portions of the marrow,with a capsule of connective tissue and with towards the periphery gradually increasing density and in which large hyalinized areas are found. At the marginal zones of this capsule the formation of new bone in the sense of marrow callus is observed in an almost uniform progression unto the fracture site. The newly formed bone trabeculae reveal a normal structure. We have to deal with endosteal marrow callus and intermediary callus. Next to this zone of newly formed bone lies the zone of the compacta of the tibia with signs of lacunary resorption, which are limited to the area of the fracture site (see illustration 15). In the immediate proximity of the fracture site the Haversian canals are dilated and contain besides a subtle network of fibrin and vessels perivascular small cell elements. A more or less distinct formation of bone was observed in the slightly enlarged Haversian canals.

Sharply contrasting from this compacta zone we observe a larger area of periosteal bone deposits. Towards the outside we have tight connective tissue. We have to deal here with periosteal callus.

Microscopic findings at some distance from the fracture site: The general picture is the same with the exception of the periosteal bone formation which is not present here. The differentiation of the different zones from the center to the periphery as described above is still more distinct under the microscope. The central parts of the bone marrow have undergone a change into inflammatory granulation

tissue which loosens up peripherally to change over to a compact lining of connective tissue in which the inflammatory cells gradually diminish. In the peripheral zones of this lining of connective tissue we also find in the microscopic examination, distant from the fracture site, endosteal formation of new bone in the form of well developed bone trabeculae. Next to it lies the large compacta zone and the periosteum, both without abnormal findings.

The condition may be described as a purulent inflammation of the central parts of the bone marrow. This inflammation is limited to the site of the former nail bed. In the peripheral areas of the marrow the inflammation is limited by granulation tissue to such an extent that here a compact connective tissue envelope has developed. Only in the area of the fracture site do we find a pronounced inflammatory infiltration in the place of the bone marrow. Proper abscesses are not to be found. Under no circumstances do we find the condition of a medullar phlegmon with total destruction of the bone marrow. The compacta reveals only in the immediate proximity of the fracture site a pronounced porosity caused by lacunary resorption. The periosteum is not invaded by the inflammation. We observe here a new formation of bone in the sense of a fresh but intense formation of callus in the area of the fracture site. Disintegration is certainly present but in most of the cases we find augmentation of callus and the formation of intermediate and marrow callus. Marrow callus is also formed in the peripheral areas of the marrow remote from the fracture site. Signs of disintegration are also observed here. A periosteal regeneration of the bone is also observed in areas remote from the fracture site.

From the description of the various conditions it appears that a medullar phlegmon with a possibly totally destroying suppuration had occurred in none of the cases. As has been explained in detail the fear of these phlegmons is as a rule not justified in compound shaft fractures. The rare occurrence of marrow phlegmons has so far been observed only in the marrow nailing of closed fractures.

With regard to the bone regeneration after the infection following the marrow nailing operation H. REICH on the basis of the above histologic findings has the following opinion:

The histological preparation reveals that even in the case of an active and still fresn inflammation as set forth in the first of the described cases (complicated femur fracture of a patient, 56, who died three weeks after the accident from a lung embolism), regeneration does not come to a standstill. Fresh callus formation was observed in the bone marrow and periosteum. The inflammatory processes stand, however, in the foreground, especially in the proper zone of the fracture.

If the infection of the bone lasts for 9 weeks it can also be determined that callus formation is in process. It is found, however, that no purposeful formation takes place. Accordingly we find an irregular variety of freshly formed osteoid and older callus which bears again the signs of disintegration. The symptoms of the disease are determined by the inflammatory processes of the fracture site.

In case of a pertrochanteric thigh fracture, the inflammation of which lasted for 13 weeks, no signs of a beginning callus formation could be traced. Only inflammatory changes could be observed at the fracture site. The reparative processes which always are considerably slower in the spongiosa than in the long bones, have been delayed additionally by the infection of the bone and the marrow nail in position.

A distinct regeneration is observed in the last of the described cases pertaining to a complicated tibia fracture of a man, 60, whose infection had been lasting more than 4½ months. This regeneration took place although pronounced inflammatory processes could still be observed at the fracture site. A ring shaped sequestrum developed in this case. After its removal a strong callus formation in the marrow as well as in the periosteum set in. The conclusion may be permitted in this case that a complete regeneration was within the realm of possibility. Also in this case it could be ascertained that a pronounced callus formation had started in the peripheral area of the marrow, remote from the fracture site. We have to deal here with a peculiarity of the marrow nailing which simultaneously indicates the onset of regeneration which in turn leads to the healing of the fracture.

As set forth by the histological examinations the callus formation is minimal or delayed by the nail in position in case of an inflammation as long as the inflammatory processes stand in the foreground. When the inflammatory process subsides, regeneration sets in. It is rather surprising and at the same time typical for the marrow nailing that the regeneration ends in solidification of the fracture. The healing is purposeful and follows a well organized plan. The participation of the periosteum is particularly evident. An important factor is the perfect position at rest as achieved by the marrow nail.

The final healing results of the complicated and infected fractures treated by marrow nailing can successfully compete with the results achieved in other methods. They are even superior according to the statistics of H. REICH. The time of healing is on the average shorter with the marrow nailing method and the care of the patient is facilitated. The number of severe infections is no higher. According to the statistics of H. REICH, 89.3% of 25 compound tibia fractures could be healed completely. KUNTSCHER had no fatal case in 66 marrow nailings of already infected fractures. These healing results are dealt with in detail in Chapter VII and in the description of marrow nailing of compound infected fractures where detailed statistics are given.

CHAPTER V.

Technical procedure in marrow nailing of simple fractures.

I. General remarks.

A. Indications for marrow nailing of simple fractures.

Percutaneous marrow nailing means driving the nail in without exposing the fracture site. Thus any possible danger or disadvantage in connection with an open procedure can be avoided. This justifies making the widest possible application of the method and, if there is no contra-indication, to treat all suitable fractures by this method. Thus the number of operative exposures may be considerably reduced because many fractures have to be operated due to the originally exact fixation being lost in the plaster of Paris cast or traction fixation. Unfortunately, statistical data emphasizing this fact are not available at the time of writing.

The author, as well as the Kiel Surgical Clinic, support such widespread use, and it would appear that most of the surgeons who use the method such as BOEHLER, HAEBLER, EHRLICH, etc. take the same view. Contra-indication is considered justified - - as has already been mentioned in chapter IV - - only in the case of shock, circulatory deficiency, poor condition of health, fat embolism or increased liability of its occurrence, suppurations, old wounds, and burns. According to BOEHLER, tabes is no contraindication unless there are other reasons, while severe diseases have to be considered as a contraindication. Advanced age is no contra-indication. It is especially in these elderly patients that the advantages of the method are particularly spectacular. After marrow nailing of simple fractures of the lower extremities of elderly people the author has them to get up for a short while on the day following the nailing to offset the danger of pneumonia and weakening of the circulatory system. Advanced age therefore is no limitation in the indication for marrow nailing. There is, however, the opposite tendency in treating fracture of children.

Marrow nailing of children.

Children up to the age of 14 years should not be marrow nailed unless quite special reasons speak for it. Children are never endangered by a stiffening of the joints even if kept immobilized for a very long time, and they are also not endangered by pneumonia or disturbances of the circulatory system due to prolonged confinement to bed. In addition, during the growing up period the juvenile organism will adjust in an astonishing way for even badly reduced fractures. Of course there are limits as for instance marrow nailing may be given preference rather than

to risk shortening of a limb when it is doubtful that the shortening may be completely overcome later, more so as risks or technical difficulties in marrow nailing of children do not exist. BOEHLER, it is true, thinks of osteomyelitis as a possibility arising when using the marrow nail with children. However, this danger is presumably no greater than in wire extension. The nail, in any case must pass thereby through zones of growth. This, however, as seen from chapter IV, does not cause any disorder. Also one need not be concerned about the blood count (see chapter IV).

Sufficient experience with the marrow nailing of children is available and even infants no older than 2 years have been nailed by using sufficiently thin nails. Various examples of nailing fractures of children are referred to in this book (see chapter IV and V).

Some surgeons limit the indication for marrow nailing to a substantially smaller range. They restrict marrow nailing to only those fractures which according to former experience may cause difficulties if treated by any of the other methods. They pick out distinct transverse fractures which frequently heal with a lateral displacement and tend to refracture, or fractures of the lower third, of the femur where the power of the quadriceps can hardly be overcome and which tend to angulate forward. Finally those fractures which can be easily reduced but which cannot be kept in the reduced state, as they tend to slip off again, i.e. fractures which otherwise would come into consideration for open reduction.

Surgeons who want to become acquainted with the marrow nailing method may begin by nailing fractures which are best suited for this method, i.e. transverse fractures of the middle portion of the femur, leg and humerus. Thus the peculiarities of this method are best appreciated. Only at a later stage is it recommended to practice the more difficult marrow nailing of the forearm and of the oblique fractures, etc.

B. Fractures suited for marrow nailing.

It is solely a problem of technique to recognize whether or not a fracture is suitable for marrow nailing. It depends on the form and position of the fracture and whether or not it is possible to bring about a compact permanent union, i.e. a stable osteosynthesis. All those fractures are suitable that can be firmly fixed by a marrow nail. The nail must be fixed snugly into both fragments by the force of the driving in and its own springiness in accordance with the prescribed nailing principle. Only when this manipulation is accurately performed can one speak of marrow nailing and only then will the described advantages of the procedure become obvious to their full extent. The marrow nail must project for $2\frac{1}{2}$ to $3\frac{1}{4}$ inches in both fragments.

a. Stability of the osteosynthesis depends on the position of the fracture.

Conditions conforming to the afore mentioned requirements are best in the case of simple transverse fractures of the middle portion of the femur. The marrow cavity of the femur is shaped like a cylindrical tube which in its middle part is about equal in width, only towards both ends is it slightly enlarged. If this middle third is broken the marrow nail can be fixed to a sufficient length in the two equal sized shafts of both fragments (see illustration 51).

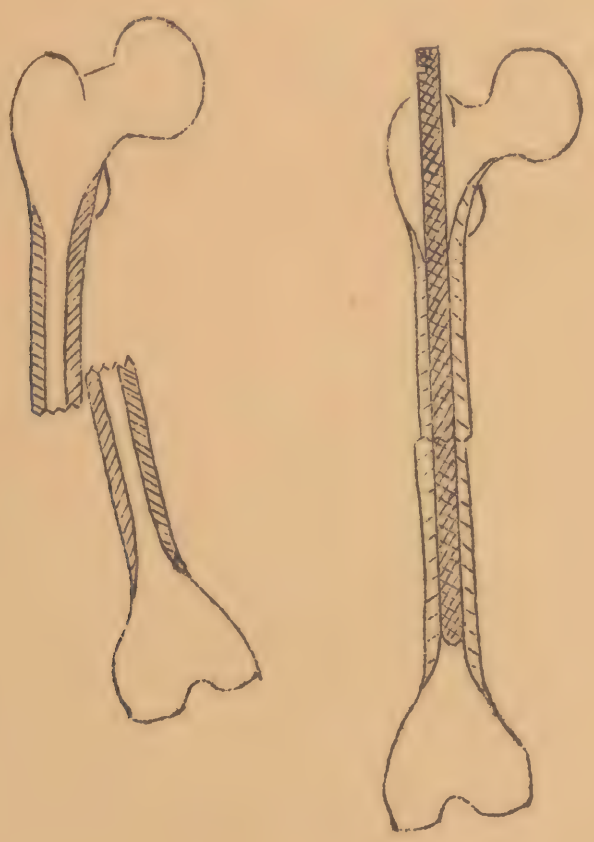


Illustration 51.
Stability of the osteosynthesis depends on the position of the fracture. This fracture is very well suited for marrow nailing since it is a transverse fracture in the middle portion of the femur. The nail can be fixed sufficiently deep in the two equalized shafts of both fragments.

If the same form of transverse fracture is located a hand's breadth nearer to the knee-joint the marrow nail would extend only 1¼ inch into the cylindrical part of the marrow cavity. This is too short a length to guarantee sufficiently elastic fixation by the nail. In such a case the marrow nail does not act as a nail, its effect is that of a pin which undoubtedly excludes lateral displacement and also angulation, as well as shortening.

Yet the pin cannot prevent the distal fragment from rotating, just as the pin in the hinge of a door allows the door to swing. None the less the osteosynthesis can be considered as stable clinically because all the surfaces of such transverse fractures are never perfectly even. They always have small notches and bulges which after careful reduction fit into the respective niches of the distal fragments. It is peculiar to this process that the reduction accurately regulates itself. The pull of the muscles presses these notches and niches against each other which prevents rotation of the fragments (see illustration 52).

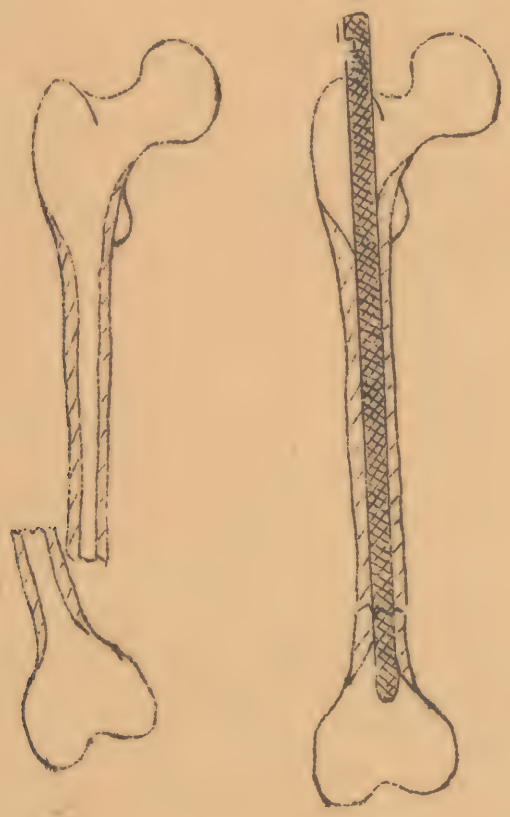


Illustration 52.
The stability of the osteosynthesis depends on the position of the fracture.
This is the same fracture as in illustration 51, yet it is considerably nearer to the knee-joint. The osteosynthesis is stable though the marrow nail goes only 1¼ inches deep into the distal fragment. Angulation, lateral displacement as well as rotation are excluded due to the pull exercised by the muscles upon the fragments.

If there is no jagging and the surfaces of the fragments are relatively smooth, as for instance in the saw-cut surface of an osteotomy or joint-surface of an old pseudarthrosis the osteosynthesis will not be stable even in the presence of strong muscle pull. So also in the case of a jagged surface if the muscle pull is weak, which

was observed by HAEBLER in one case of a fractured humerus.

If this transverse fracture was still nearer to the knee-joint, the osteosynthesis would be quite unstable because the marrow cavity is considerably enlarged there. A lateral displacement of 1 to 1½ cm might be possible and the distal fragment exposed to the risk of being angulated anteriorly or laterally towards either side (see illustration 53).

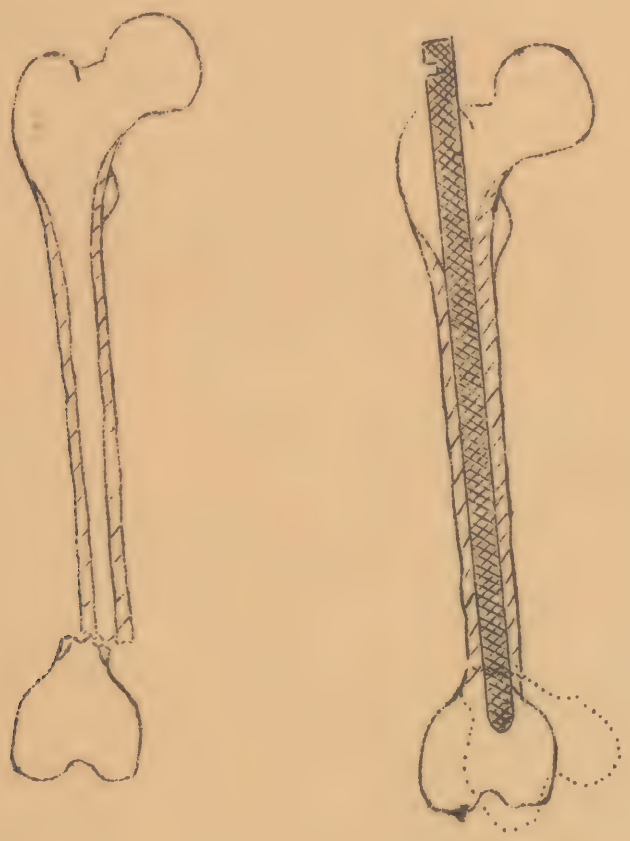


Illustration 53.
Stability of the osteosynthesis depends on the location of the fracture.
This is the same fracture as shown in illustration 52 yet a little bit nearer to the knee joint. Now osteosynthesis is no longer stable. Lateral displacement as well as angulation are possible.

All the same the method is of use even in cases like this. The marrow nail is always in contact with the corticalis of the front wall due to the flexors of the leg being stronger, and pressing the distal fragment upon the point of the nail. It is just for this same reason that with the plaster cast or the traction method such fractures offer great difficulties because the distal fragment is angulated backwards. This can be avoided by nailing, as already indicated. By applying an additional plaster sleeve lateral displacement and angulation may also be

counteracted (see also chapter VI).

If, however, the same fracture is still closer to the knee-joint, it is easily understood why even this last advantage no longer holds good.

b. Stable fixation depends on the anatomical shape.

General rules cannot be established as to what distance from the joint cleft stable fixation is no longer possible, because the distal enlargement of the marrow cavity varies in each individual case. In exceptional cases this considerable enlargement begins only just above the knee-joint, so that fractures even next to the joint make osteosynthesis possible without additional plaster casts being required, yet such cases do not permit any weight bearing (see illustration 54).

a b

Illustration 54.
Stability of the osteosynthesis depends individually on the anatomical shape.
a) Common shape of the distal end of the femur which makes stable osteosynthesis impossible (see illustration 53).
b) Exceptional shape where osteosynthesis is possible, it needs an additional plaster cast and does not permit any weight bearing.

In the ulna the marrow cavity is wide distally and then narrows rapidly. Proximal fractures are advantageously treated with conical nails for this reason (see illustration 55).

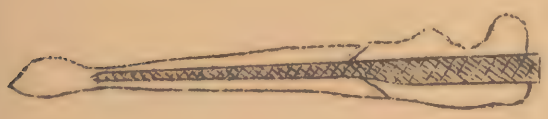


Illustration 55.
Owing to the anatomical shape of the ulna proximal fractures are to be treated with conically shaped marrow nails - as described by MAATZ.

c. Stability of the osteosynthesis depends on the type of the fracture.

1. Transverse fracture.

All essential matters regarding this subject have been stated in Section A of this chapter.

2. Oblique fracture.

If in place of the transverse fracture as in illustration 51 an oblique fracture of the middle portion of the femur comes into consideration, a perfectly stable osteosynthesis will also be possible even if the line of the fracture is quite steep. In the absence of any jagging it is just this steepness which is a safeguard against any rotation (see illustration 56).

Illustration 56.
Stable fixation depends on the type of the fracture. Stable osteosynthesis of an oblique fracture of the middle portion of the femur (see illustration 51).

If the fracture is more distally situated like the oblique fracture of illustration 52, stable fixation will also be possible. By the pull of the muscles the fragments are pressed together so that alongside the oblique fracture surface a shifting takes place until the medial corticalis of the distal fragment comes into contact with the marrow nail. This means a shortening by ½ to 1 cm., which is of no practical importance. Further shortening will not be possible. And so also no angulation, rotary displacement, as is to be seen from illustration 57.

Illustration 57.
Stable fixation depends on the form of the fracture. This is a distal oblique fracture of the femur, the position of which corresponds to that shown in illustration 52. A slight shortening has resulted. The pull of the muscles and the oblique surface of the fracture impede any further displacement and therefore the osteosynthesis is stable. It will permit weight bearing. Yet still more distally located oblique fractures will not be suited for the method.

3. Multiple fractures.

As to their suitability for marrow nailing multiple fractures are to be considered according to the following circumstances:

a - breaking away of a tube-like fragment, so-called double fracture,

b - breaking away of one or more fragments, whereby part of the bone-tube remains intact - - typical example: the classical bending fracture with breaking away of a so-called bending triangle.

c - comminuted fractures and demolition of the bone-tube (comminuted fractures).

As to circumstance a ordinarily the middle portion of the shaft is concerned and a sufficiently stable osteosynthesis can be obtained. The tube-like middle piece broken away is as it were "strung" upon the marrow nail (see illustration 58).

Illustration 58.
Stable fixation depends on the form of the fracture. In multiple fractures where a tube-like middle piece has broken away, a sufficiently stabil osteosynthesis can usually be obtained.

b - Multiple fractures where part of the bone-tube has remained intact can be united only, if the fracture is in the middle portion of the shaft. Thus the marrow nail can get sufficient hold in both the distal and proximal fragment and the synthesis is fully safeguarded against any rotation. Shortening is also safely prevented

due to the presence of the intact remnant of the bone-tube, even if that piece is very narrow (see illustration 59).

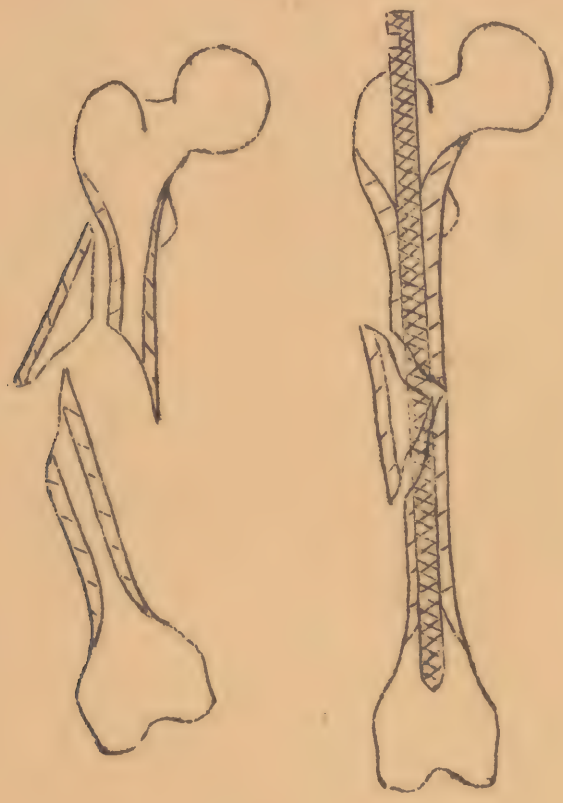
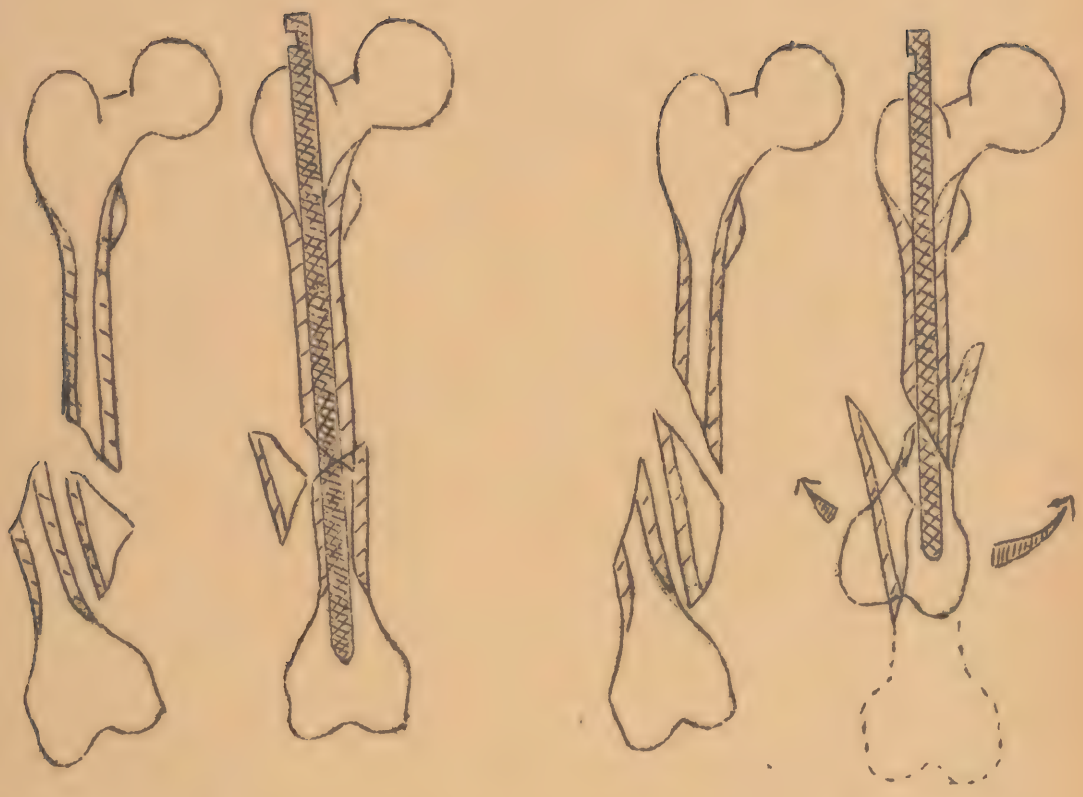


Illustration 59.
Stable fixation depends on the form of the fracture. Multiple fracture where part of the bone-tube has remained intact can be firmly united if the fracture is in the middle portion of the shaft; this is also an absolute safeguard against any shortening.

Yet if the position of this fracture is more in the conical part of the marrow tube, shortening will be possible because the upper end of the proximal fragment may penetrate deeply into the distal fragment. This is impossible in the case of simple transverse fractures, even if very thin nails have been used, because the open sides of the marrow cavities of both fragments are equal in width. The shortening depends on the form of the fracture as well as the anatomical shape of the bone. Most shortenings are trifling. It is due to the fragments being driven telescope-like one into the other and then wedged by the nail that satisfactorily stable osteosyntheses are obtained. Should the surface of the fracture differ even by a little in shape it may be impossible to obtain a satisfactory result (see illustration 60 a and b).



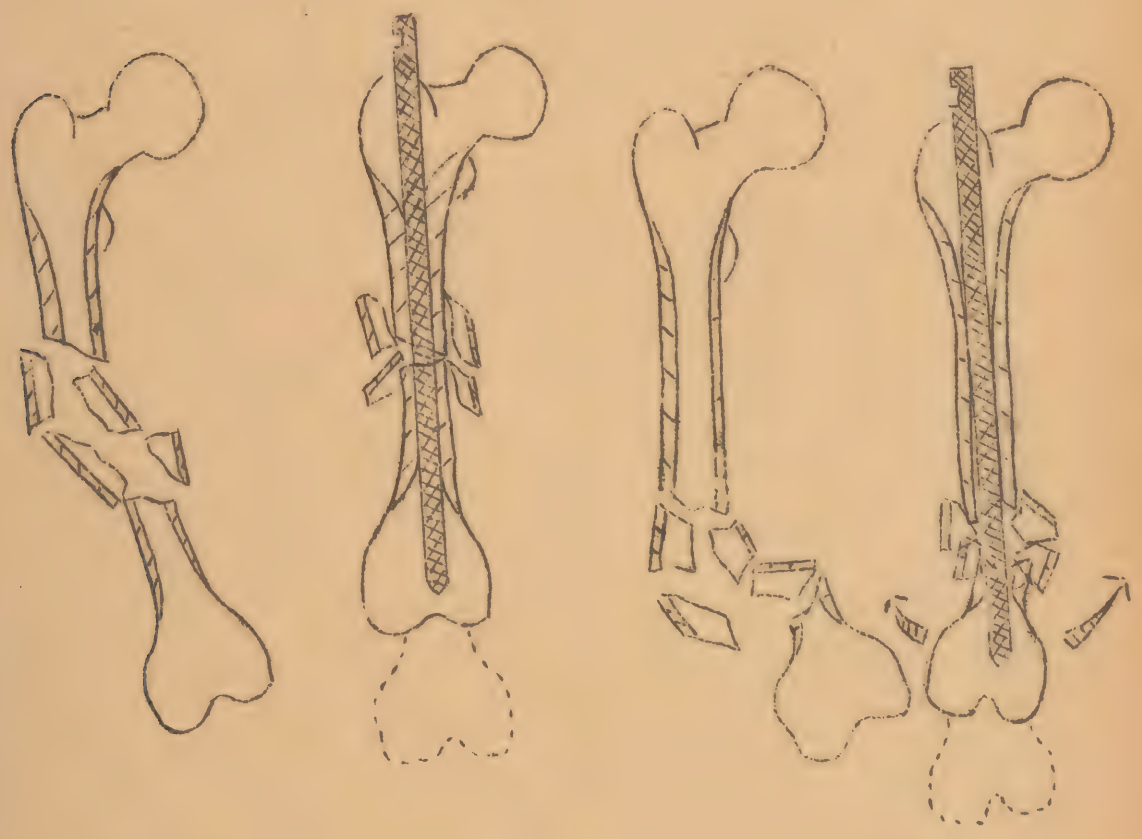
a b

Illustration 60.
Stable fixation depends on the form of the fracture.
a) this is the same comminuted fracture as shown in illustration 59, yet more distally located. The fragments are telescope-like interlocked one into the other and wedged by the marrow nail. Thus a stable osteosynthesis is obtained but a shortening by 1½ cm. also results.
b) Similar fracture. However, the surfaces of the fracture stand somewhat steeper so that the fragments cannot be wedged together. This makes a stable osteosynthesis impossible.

By both examples it is shown clearly that such oblique fractures have to be subjected to careful consideration. In addition they require more practical experience and technical skill. Another conclusion is the impossibility to give more than a general outline regarding suitability of fractures for marrow nailing as all kinds of fractures that may occur cannot be dealt with.

c - In comminuted fractures an osteosynthesis will be possible if the comminuted area is in the middle portion of the shaft. Lateral displacement and angulation

is impossible and so healing in the proper axis is ensured. Yet this osteosynthesis is in no way safeguarded against rotation and still less against shortening! Therefore it is indispensable to apply an additional plaster cast or extension bandage. Even if by so doing weight bearing at an earlier date may be possible, the advantage of marrow nailing in such an instance is usually insignificant (see illustration 61a). If the comminuted area is in the conical part of the bone-tube a marrow nailing osteosynthesis will be quite impossible (see illustration 61b).



a b

Illustration 61.
Stability of the osteosynthesis depends on the form of the fracture.
a) Comminuted fracture in the middle portion of the bone-tube will result in a synthesis which prevents lateral displacement and angulation but not shortening and rotating. An additional plaster cast or extension bandage is necessary.
b) Comminuted fracture in the conical portion of the bone-tube is not suitable for marrow nailing.

Individual remarks regarding suitability of fractures of the different tube bones are stated in the Special Part -II- of this treatise. It is also mentioned there how, by using specially formed nails in certain

cases, even fractures in the conical, distal or proximal part of the bone-tube, which have just been designated as less suited, can be made suitable for a stable osteosynthesis.

Stable osteosyntheses can be established only if the marrow nail can be wedged firmly in the corticalis of both fragments. If it is embedded in the network of the spongiosa, any motion, even with slight force, may cause some of the bone trabeculae to break and this makes room for further motion. Increased forces can never be sustained by the spongiosa. Then quite the same conditions are given as in nailing fractures of the neck of the femur. If in the nailing of less suitable fractures BOHLER recommends driving the nail into the spongiosa he thinks of the nail as only a supplementary safety measure. Those cases where the nail lies entirely or for most of its length in the spongiosa of one or even both fragments cannot be considered as true marrow nailings, and the advantage of the method can only partly be claimed for them. This is particularly true, if infection occurs, as an extraordinarily rapid loosening of the osteosynthesis and wandering of the nail results.

All the same it may be possible that rather good osteosyntheses will be obtained in isolated cases. In the pertrochanteric fractures the nail sticks almost to its full length in the neck and head. Thus the weight bearing surfaces are sufficiently large to bear the full weight of the body at a very early date, though those areas belong exclusively to the spongiosa. (See chapter V). In nailing fractures of the neck of the humerus the nail can also be fixed sufficiently firm unless the joint is in a stiff condition, because increased forces cannot become effective at the proximal part of the bone, due to its head following any movement. (See chapter V).

Special conditions prevail in regard to the clavicula. A marrow cavity in the proper sense does not exist, the shaft being completely filled with spongiosa. Yet the walls of the shaft tube have a compacta so thick and strong that the nail can get sufficient hold and one can speak of a true marrow nailing.

C. Instruments used in marrow nailing.

Nails used for marrow nailing have been treated in the special part of this chapter in connection with the marrow nailing of the respective bones, and implements for removing them in the chapter "Removal of marrow nails".

Hammer.

This is the most important tool. The ordinary carpenter's hammer with square head face and a wooden handle has proved best. Its shape has been developed by centuries

of experience, hand and eyes are accustomed to that shape and to the distribution of weight between head and handle. The wooden handle can be made sterile by boiling it sufficiently, just like a metal handle, and in spite of its frequent boiling its lifetime can be expected to be a long time. There is no necessity to replace this wooden handle by a light-weight metal tubular one. The outstanding point is to use a hammer that is not too heavy in weight. In any case it must not be heavier than the hammer in use for removing the nail as otherwise withdrawing the nail again with this hammer may be impossible. The weight of the hammer to remove the nail is 1 lb + 7 oz. The weight of the hammer to drive it in is therefore, to best advantage, not more than 1 lb + 2 oz approximately. Of course, by using a heavier hammer it may be possible to overcome greater difficulties arising from a disproportion between the thickness of the nail and the width of the marrow cavity. Certainly such nails also have a better hold. But by driving them in, the bone and the tissue are much more violently disturbed. Practice has shown, that even in the femur, osteosyntheses obtained by the 18 oz hammer are quite sufficient in stability. Should this hammer fail to drive the marrow nail forward even with heavy blows it will be better in most cases to have the nail pulled out again rather than using a heavier hammer (see illustration 62).

Awl.

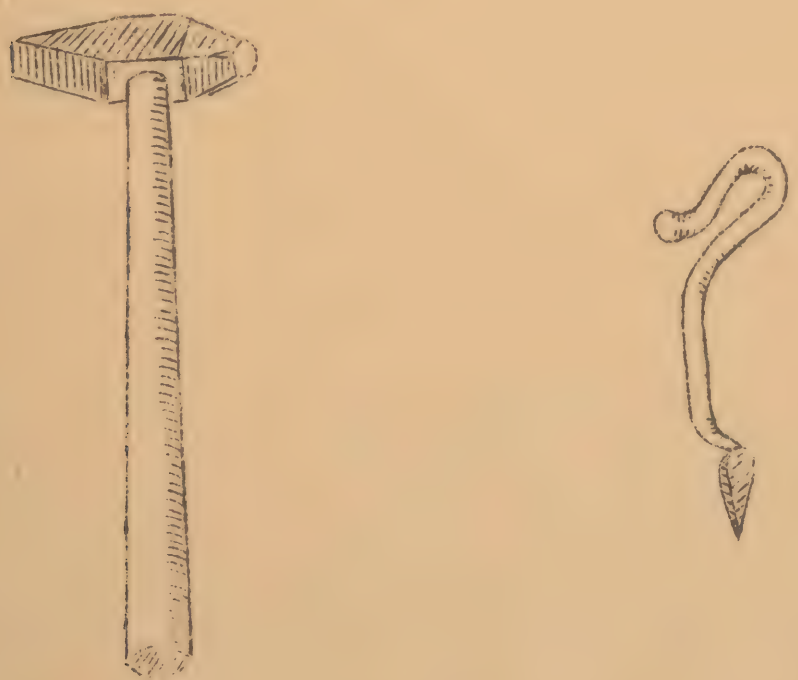
The act of driving the nail in is to be preceded by obtaining access to the marrow cavity. This is achieved by boring a hole into it. The hole will always be in the spongy part of the bone - the only exceptions being in distally nailed femurs or in nailing the clavicle - and a thin layer of the cortex has only to be pierced. The most simple way of boring the hole is by means of an awl. This will not generate heat in the tissue as does an electric drill and thus no heat necrosis of the bone can arise, which is often observed even on the holes bored for Kirschner wires, as has been shown by RUECKERT. Besides, the awl facilitates maintaining the direction wanted in boring. Moreover, the awl is of special advantage in marrow nailing as it permits one to observe the moment the marrow cavity has been reached, because the awl is unable to penetrate into the solid wall of the substantia compacta. Therefore the latter cannot be injured or pierced, as may easily be possible with an electric drill. The awl acts like a power lever with a large gear ratio. If its cutting edge is 5 mm. in breadth and the handle 10 cm. in length, the ratio of transmission will be 1 : 20, i.e. it will be possible to remove any little protuberant parts in the bone with 20 times the physical power available by turning one's right hand. In most cases it will also be possible to pierce the sealed ends of the marrow cavities in a pseudarthrosis. The handle of the awl is bent, so that when boring the hole for marrow nailing of the leg, the knee-joint is not a hindrance (see illustration 62).

Drill.

The awl will not suffice to pierce the hard and firm substantia compacta and the closures of marrow cavities of eburnated bones. Hand-drills or better still electric drills should be used with crown- or twist-drills of various sizes. An extension attachment to the drills will also be of advantage to enable a widening of certain passages of the marrow tube which may be too small in width. Thereby, it is true, the tissue of the marrow is completely destroyed at the respective places. Yet as per investigations made by the author and referred to in chapter III, this is of no influence whatever on the healing of the fractures and to the functioning or vital power of the bone. But the heat which is produced in electric boring is of influence and in a most detrimental way. For that reason, E. POHL has constructed very useful drills especially for marrow cavities, which avoid stronger heating (see illustration 62). The hole is first prepared with a thin drill, and then widened by means of a bigger one. Another advantage of these drills is that the hole cannot be bored towards a wrong direction which possibly bends laterally from the marrow cavity. (See illustration 62.)

Countersink devices.

In order to make the marrow nail disappear below the surface of the skin a countersink device is needed in the last phase of driving the nail in. In order to prevent the countersink device from sliding off the nail's head it is provided either with a grooved surface or a punch. In the first case the device can be used for all nails, in the last one in all cases except for forearm nailing (see illustration 62). The length of a countersink device is 100 mm. and the width 10 mm.

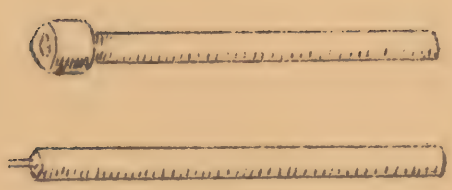


Hammer — Awl

Illustration 62.
Instruments used in marrow nailing.

Drill

Drill extension attachment



Countersink device with grooved surface,
Countersink device with punch.

Illustration 62.

In percutaneous marrow nailing of a few bones some other special instruments are needed. They are described in the Special Part of this treatise. As far as marrow nailing is applied to osteotomy, as it is decribed in detail in chapter VI, the implements used in these operations will also be needed. In all these cases the surgeon will use those instruments with which he is best accustomed. Giving minute descriptions of all of them may be omitted. In osteotomy the marrow nailing is executed only by sur-

geons specially skilled in bone operations and they know the instruments very well. Therefore they are listed here summarily only: Bone-saws, flat and hollow chisels, large and small Luer rongeurs, Lambotte raspatories, ordinary raspatories (width especially recommended 3-4 cm.) ordinary lambotte bone-holding forceps with lock, Hohmann bone-lever, heavy single-pronged Langenbeck hooks, flat forceps and wire-cutters, boring jig for clamping Kirschner wires in the electric drill, metal rulers, Kirschner wires, V2A wire of various sizes.

Marrow nailing must not be commenced without the entire set of instruments being complete and ready! Also included should be instruments to remove the nail and a metal saw to cut off the nail if necessary, as well as a sufficient supply of nails varied in size, and the Roentgen apparatus and its accessories.

D. Reduction.

It is due to the peculiar nature of this method that the reduction must be performed far more accurately than necessary in all the other methods. If the apertures of the marrow holes of both fragments cannot be approximated, so that they are almost facing one another, the nail cannot be introduced whereas a fracture healed with a displacement by a shaft's breadth in a plaster cast is considered a favorable result unless there is a marked shortening and an angulation. On the other hand, the reduction need not be as accurate as the millimeter, it will suffice if at least a guide-wire, a guide-rod, or the conical shaped point of the marrow nail enters the other marrow cavity. The last phase of the reduction, i.e. the adjusting, sometimes up to a tenth or a hundredth of a millimeter in exactness, is regulated by the nail itself. In gliding down the marrow tube the point of the nail automatically makes both fragments slide one upon the other so that their cylindrical parts fit exactly together. Any angulation is also automatically removed thereby. Yet rotation is not corrected. Therefore before definitively driving the nail into the end particular care must be taken that the position in regard to rotation is correct. (See illustration 63).

As a consequence of the introduction of marrow nailing, new methods to enable accurate reduction were developed. Reduction by manual power easily fails due to the heavy drain of energy required thereby, or if manual power is too weak to hold the reduction until the act of marrow nailing is completed. This resulted in developing a series of new apparatuses.

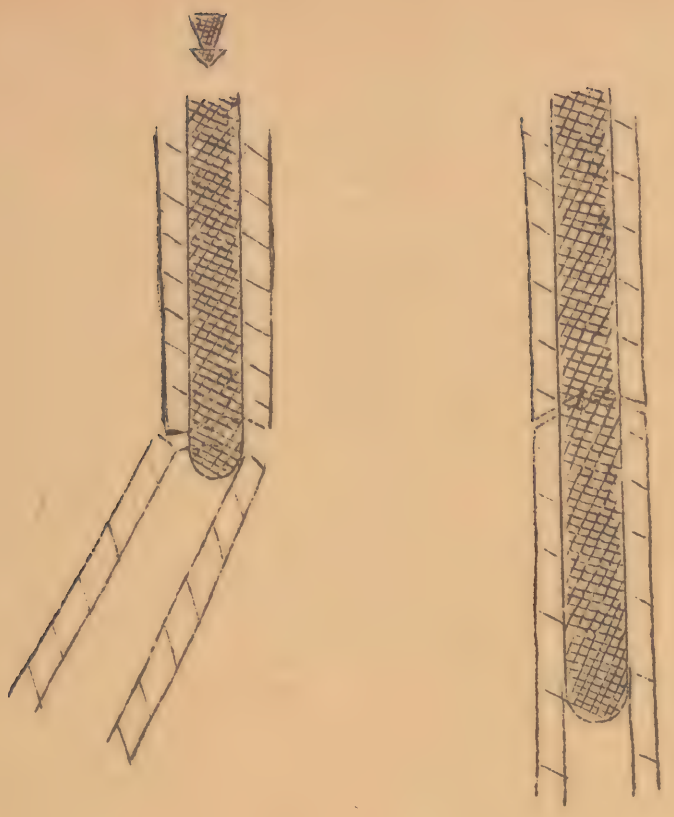


Illustration 63.

Automatic adjustment to utmost exactitude of any lateral displacement and angulation remaining, due to the gliding down of the conical point of the nail. However any rotation still left does not adjust itself automatically, but must be adjusted by the assistant surgeon.

The reduction apparatus used in marrow nailing.

The purpose of all such appliances is to correct shortening by the use of mechanical means such as male screws or pulley blocks. In addition lateral displacement is intended to be adjusted by levers, male screws and pulley blocks. An absolute requirement for all these appliances is that sufficient space be left free at the fracture site to allow fluoroscopic control, or that those parts of the appliances that are close to the fracture site are penetrable to X-rays.

LINSMEYER and BOEHLER reduction devices.

The LINSMEYER device is based on an ingenious idea. LINSMEYER uses stable and very broad bandages that can be

coiled around spindles fixed alongside the extremity. The spindles are furnished with strong handles, a cog-wheel and a ratchet, and they are adjustable for height. Thus a lateral pull can be made in any direction wanted and upon each of the fragments separately (see illustration 64).

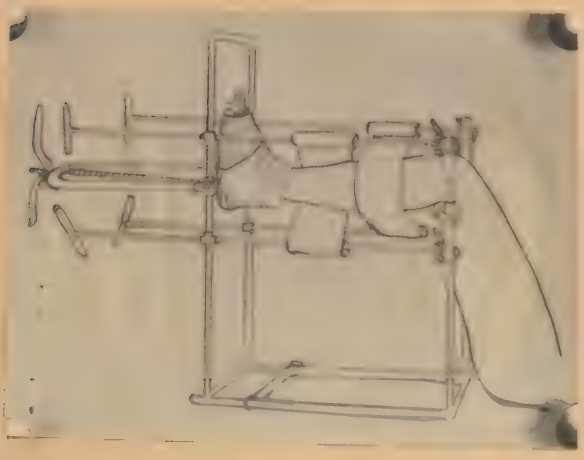


Illustration 64.
Schematic drawing of the LINSMEYER reduction device. Lateral shifting is done by coiling a bandage on to a spindle which is controlled by a cog-wheel and a ratchet.

The bandages are roentgenolucent. The spindles in connection with the strong handles form a strong gear power, thus a strong continuous pulling power can be developed. BOEHLER employs the LINSMEYER spindles in his apparatus.

LINSMEYER gives the following description of his apparatus: I have used the BOEHLER device in order to be able to exert simultaneously with longitudinal traction also lateral traction in every direction. The re-modelled screw traction device has been constructed on a duplex compound frame of strong strap-iron. It has at the top two slanting iron pipes which carry, adjustable for height, the supports for the bend of the knee or the perineum. These are Z-shaped for the bend of the knee, as described by BOEHLER; for the perineum a thicker, cylindrical model is used. The necessary longitudinal traction is produced by a strong male screw at the base of the device. It has a pin movable upwards to the desired height. The latter is flexible by the rotation of the spindle at the foot side. The foot, bearing a leather shoe, is fixed by a suitable clamp to the end of the pin and thus the traction of the screw is transferred to the leg to be stretched. In the midst of the base of the device a couple of rails are fixed carrying a small carriage moving on rollers and having a clamp. To this the Roentgen tube is fastened which permits moving it and it places the fluoroscope screen above the extremity. In order to perform in addition to longitudinal traction also lateral and countertraction in any direction, as is necessary to obtain exact fixation of a broken femur or leg, an attachment was made to the BOEHLER screw traction device remodelled as described before. It consists of 4 iron supports joined to each other which can easily be fixed at the bottom of the apparatus. At both sides 4 steel shafts, 23½ inches in length, are fitted alongside. They revolve and have a ratchet attachment. Around these shafts a couple of bandages are wound in the opposite direction. If the shafts are turned the bandages either are wound up or off and thus a minutely controllable traction can be applied in the direction wanted, either laterally, upwards or downwards. The way the fitting of the shafts has been arranged facilitates lateral fluoroscopic control with the Roentgen apparatus placed at the side.

If the leg is nailed the patient must be in dorsal position, the knee flexed, just as it is with the BOEHLER screw traction device. If the femur is nailed the patient has to be put on the side, the trochanter directed upwards. The necessary extension of the apparatus to fit the femur is easily attained by reversing the obliquely upwards directed pin, which is attached to the extension spindle, and thus the distance of the hook from the perineum is increased.

For the nailing of the humerus an apparatus has been brought on the market which also is based upon the BOEHLER screw traction device for the humerus. The frame-like construction was abandoned in this case as well and replaced by a simple duplex rectangular bar. The bar carrying the forearm is movable over that for the humerus and therefore can be used for humeri differing in length. The extension device is attached to the bar for the humerus. It consists also in a pin which is fixed to a male screw. Longitudinal traction is effected by screw traction.

For lateral traction the principle of 4 movable shafts that are fixed to two frames is also applied. The bandages wound around them are unrolled by turning the shafts and thus they are extended to exercise traction or counter-traction in any direction wanted.

BOEHLER describes his device as follows:

As it is extremely hard these times, due to the lack of skilled manpower, to construct new apparatus I have added the 4 spindles described by LINSMEYER to my screw traction device for the arm and leg.

If the apparatus is drawn out to fit the leg it can be used for legs 109 cm (= 3 feet 7 inches) in length while the normal length of the leg at the inner part is 75 - 87 cm (2 feet 6 inches to 2 feet 11 inches).

For the use in marrow nailing my apparatus needs to be supplemented as follows:

1. 4 revolving duplex rods, a cog-wheel and a ratchet,
2. another male screw 45 cm (1 foot 6 inches) in length, with a foot-board,
3. a nut, the wings of which are extended to long handles,
4. a lock-nut to fix the male screw,
5. in place of the big vertical bow two vertical bars,
6. for femoral fractures another slightly curved bar, 3.5 cm in diameter (about 1½ inches),
7. for the screw traction device for the humerus another 4 duplex bars with a cog-wheel and a ratchet are needed.

ad 1. After shortening has been corrected one can correct lateral displacement in any direction with the 4 revolving duplex bars. According to needs traction or counter traction is exerted either frontally or sagitally. Yet diagonal pulling is also possible by passing both ends of

a bandage over only one of the two duplex bars. If fluoroscopic control or a roentgenographic film shows the fragments in a good position another 2 bandages may be used advantageously which in addition to frontal bracing will also firmly hold the fragments sagitally and thus impede any lateral dislocation while the nail is driven in.

ad 2. The male screw, 45 cm. in length (18 inches) may be used for femoral fractures and fractures of the leg. By means of the foot-board the foot can be firmly fixed and elasticity is eliminated. In addition to the counter-pressure the foot-board exercises will prevent the fragments from slipping off during the act of driving the nail into the distal fragment. This is supported by loosening the longitudinal traction of the guide rod in femoral fractures and the nail proper in fractures of the leg has entered the distal fragment.

ad 3. By means of the long extended wings of the female screw it will be possible to develop sufficient traction power for longitudinal pull.

ad 4. By means of the lock-nut it will be possible to keep the male screw and the foot-board in any position.

ad 5. The cross-bar has been removed from the distal bow of the screw traction apparatus to enable fixing the revolving duplex bars.

ad 6. The curved cross-bar, 3.5 cm in width (1½ inches), is padded, it is to serve as a support between the legs when longitudinal traction is applied.

ad 7. Two revolving duplex bars are connected with two vertical bars. After the vertical pipe-bars of the screw traction device for the humerus have been opened by filing the revolving duplex bars can be fitted. They are used in the same way as on the leg and femur.

The WITTMOSER reduction apparatus.

WITTMOSER uses two wooden rings adjustable by male screws. (See illustration 65).

WITTMOSER describes his device as follows:

It consists of adjustable rings (3), a sliding carriage (9) and a slide rail rim (4).

By means of the adjustable rings (3) those forces transverse to the longer axis can be put into operation which are necessary to approximate the fragments. Each of the adjustable rings is attached to a sliding carriage (9) and can be run along with the latter on the slide rail rim in a longitudinal direction ad libitum. Advantageously one of the rings is put close to the end of the proximal fragment, the other one close to the end of the distal fragment. By means of the male screws which are on the sliding carriage the adjustable rings can be moved vertically to the longer axis. The screw raises and lowers the ring,

the screw also pushes it toward the open side of the rim and pulls it back. Therefore each ring can be moved in any direction transverse to the longer axis and so also the extremity. As the limb is embraced by the ring an alteration in any direction desired is possible within a few seconds by reversing the turn of the screw to the opposite direction. The adjustable rings are wooden and roentgenolucent. They can be opened and thus readily permit placing the limb inside. In width there is sufficient room for motion that one ring can be carried past the other. It is so to speak possible to shear off the limb (100, 101). Thus any lateral dislocation of the fragments as well as angulation can be adjusted and corrected.

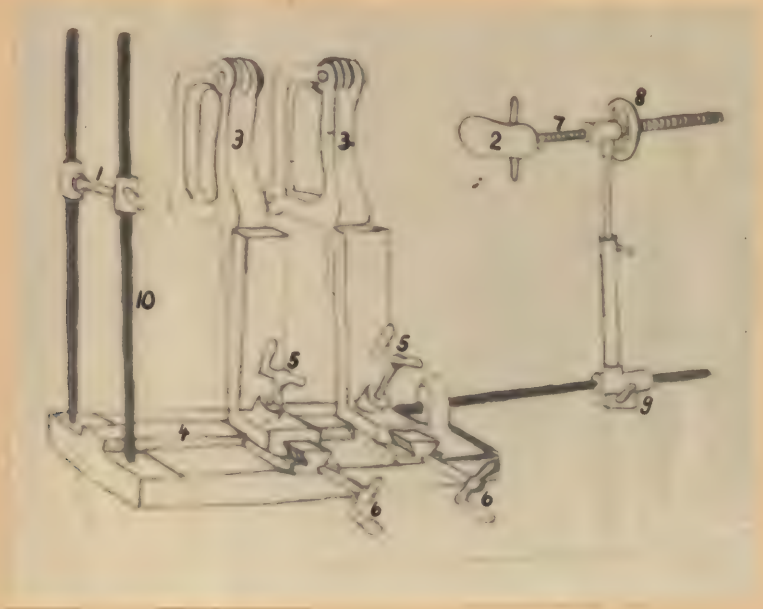


Illustration 65.
WITTMOSER reduction apparatus with overhead stretching structure.
(1) Cross-bar to serve as a support for the perineum (or for the knee-bend or the chest-wall respectively)
(2) Foot-board
(3) Adjustable wooden rings
(4) Straps with slide-rails on which adjustable rings are movable in longitudinal direction
(5,6) Male screw with crank handle
(5) Winds upwards and downwards
(6) Moves the adjustable rings forwards and backwards
(7) Pull and push spindle
(8) Hand-wheel
(9) Sliding carriage
(10) Vertical bar.

The adjustable rings (3), the sliding carriage (9), the screws (5,6) and the slide-rail rim (4) are the three constructive elements essential for the reduction apparatus. In order to obtain correct engagement of the bone ends by means of the rings any existing shortening must first be

eliminated. For this purpose one of the common extension apparatuses may be used. Therefore the apparatus is a supplement to one of the usual extension tables.

In order to be able to operate independently of any extension table the apparatus is fitted with an extension device. Appropriately modified parts of the familiar BOEHLER extension apparatus are used. The adjustable cross-bar (1) fixed to the vertical bars (10) serves as a support. It supports the perineum when applied to the femur, the knee-bend when applied to the leg and the lateral wall of the chest when applied to the humerus. Upon the foot-piece a strong longitudinal traction can be exerted by means of the spindle (7) and the hand-wheel (8). The foot piece is either strapped to the sole of the foot or to the forearm.

The pulling spindle is also used as a pressing spindle. By turning the hand-wheel in the opposite direction the pull can be reversed and changed into a pushing force.

This is an important factor in the prevention of distraction which time and again has caused trouble principally in the marrow nailing of legs. BOEHLER has emphasized how important it is in the healing of fractures to avoid distraction and so in nailing the neck of the femur he suggested forceful impaction. Although even rather large spaces may be bridged due to the impetus the action of the marrow nailing exercises upon the formation of callus, it is none the less our belief that trouble may arise from persisting distraction. For that reason, the spindle was constructed so as to allow the exertion of pressure after the nail has entered the distal fragment. The foot-piece as a support will permit driving the nail further in and thus prevent distraction from developing.

The apparatus has been made up to obtain fixation of the femur, leg and humerus and it has been constructed so stable, that power of more than 50 kgs. (110 lbs) can be developed in any direction. If no stable extension device is available the extension device as described before is to be used. Advantageously it is put on a small, low, and portable table. Thus the operative area is at a favorable working level. The top of the table has a window the size of the frame sector to allow the moving of the X-ray tube in it. The patient is bedded on an operation table the foot-piece of which is lowered. The extension device takes the place of the foot-piece. Of course the nailing can also be done on an ordinary steady table.

The place for the X-ray unit must be so arranged that one tube can work from below the table and the other one vertically to it from the side. This second tube is to be placed opposite the reduction site to enable control of the male screws in both directions from the operating stand.

When working in bright illumination the course of the nailing can be followed with the cryptoscope or by film in both planes.

In contrast to earlier practice working in darkened rooms with fluorescent screens is in some respects more advantageous: An adequate frame is fixed to the upright bars (10) and two fluorescent screens which can be moved in a longitudinal direction are fitted in, perpendicular to the direction of the X-ray beam. By means of a diaphragm the cone of the beams is so narrowed that the lead glass plate of the screen catches all of the direct radiation possible. Thus both the surgeon and his assistant are protected from any direct action of the beams. And most advantageous, the surgeons can follow on the screen the course of the approximation of the fragments, the advancing drill and nail. He will be quite independent of the assistant and his descriptive remarks when operating the cryptoscope and therefore can perform the operation more conveniently and with more speed.

The switches for controlling the tubes can be hung up beside the spindles (5,6) at the adjustment side of the device. Otherwise a foot-controlled mechanism for both the X-ray and the room illumination can be employed. Thus the control of both the X-ray tubes and the moving of the two adjustable rings by one person from the same place is made possible. After some time routine will allow one to carry out both functions in the dark and while wearing lead gloves.

When working in a dark room the surgeon himself will be able to correct the displacement after seeing beforehand to the sterile covering of the male screws. In this way he will become largely independent of skilled assistance, a circumstance which is particularly important in smaller hospitals.

The MAATZ reduction apparatus.

MAATZ describes his device as follows:

It represents, as it were, the elongated arm of the assistant in charge of the reduction. The device is quite independent of the extension table and is not attached to the latter. As the forces that act upon the extremity counterbalance each other approximately firm fastening of the device to the floor is unnecessary. Ground friction is sufficient. A coarse adjustment will place the grasping yokes at the desired level.

In order to achieve exact adjustment the forces moving the lateral handles are transmitted by a universal joint and a gear ratio to the grasping yokes. By means of this device impacted fragments can be separated, carried past each other and engaged in a favorable way, as is necessary in long transverse and spiral fractures. The crepitation of the rubbing bones is so distinctly transmitted that it can be felt in the hand of the assistant surgeon who performs the reduction. Each plane can be fixed by a regulating screw. Thismust be considered as an advantage of paramount importance primarily in oblique and overextended transverse fractures.

The semicircular, padded yokes are exchangeable according to the size of the extremity. The leather strap that has 2 large openings is wrapped over the arms of the yokes so that leather and yoke constitute a uniform ring; thus this ring consists of metal for one half and of leather for the other half. This will ensure a snug grasp on the extremity. The straps must be tightened firmly as slack will reduce the efficiency of the forces considerably. The yokes are mounted on a rotating joint in order to be approximately perpendicular to the axis of the arm or leg, thus leaving space for fluoroscopic control of the fracture site.

Fractures that require more forceful power in order to be reduced - f.i. supracondylar femoral fractures - cannot be treated with this device. Then to best advantage a pulley may be used, affixed by a hook to the wall or ceiling. The arms of the lever are too short and will not allow the use of such a strong force.

The HERZOG reduction apparatus.

The apparatus so far described corrects lateral dislocation to such a way that it can be observed by the X-ray view in both planes. By moving the spindles, screws or levers the displacement, as seen in the frontal plane, can be corrected. Similarly the dislocation observable in the lateral view is then removed by turning the respective other screws, etc. This procedure offers the advantage of permitting a rapid overall view of the situation but it also makes the device very complicated.

HERZOG realized that the power executing the reduction should be mobilized in only one plane, and that diagonally to the lateral displacement. He constructed a very simple lever by means of which the extremity can be clasped within 2 hollow rings of aluminum, that are adjustable from each other as to distance. The device can be rotated around the extremity very easily thus exercising traction in the direction of the greatest lateral displacement. The arm of the lever is rather long, thus considerable power can be exerted to promote reduction. According to information from the constructor, the device has proved very useful. The rings as well as the arm of the lever are roentgenolucent (see illustration 66).

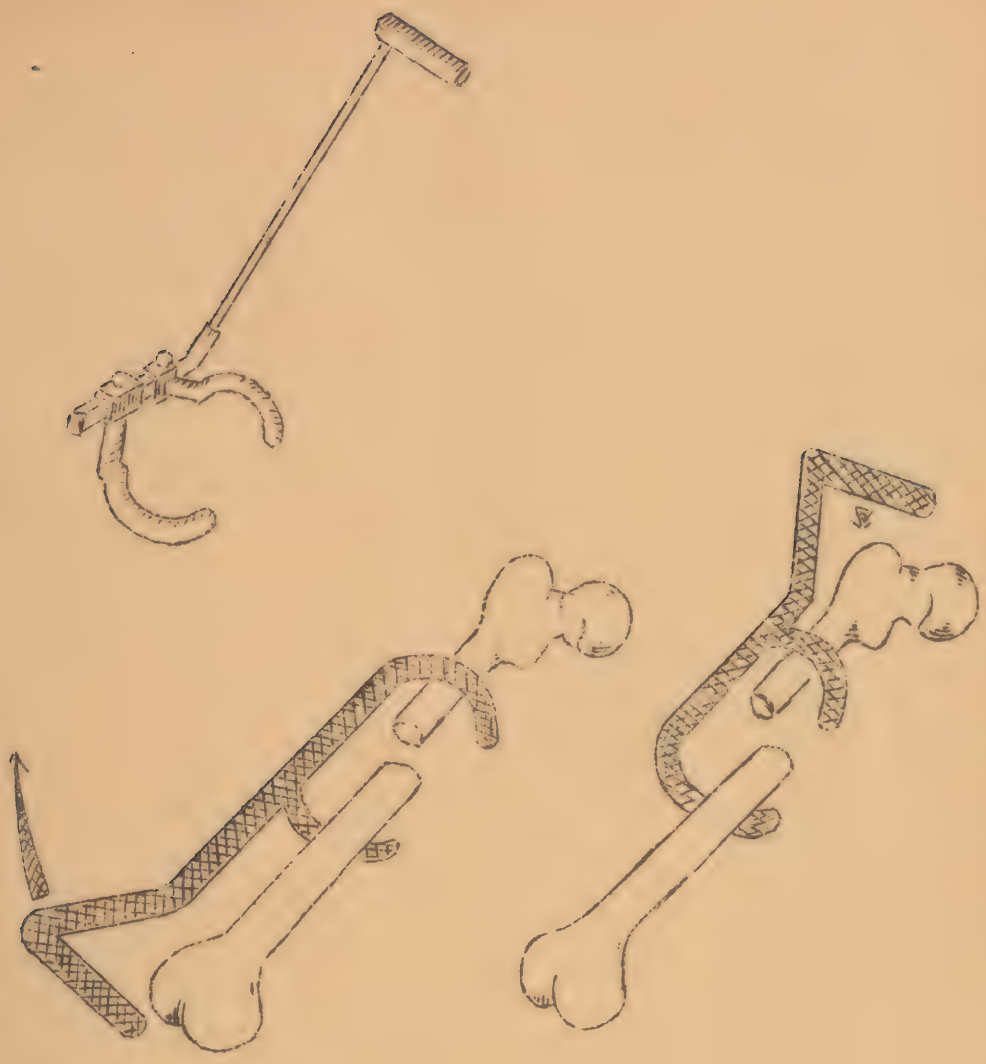


Illustration 66.
HERZOG reduction apparatus. The device can easily be rotated around the axis of the extremity in the direction of the widest lateral displacement. The HERZOG apparatus can be used for all limbs.

HAEBLER reduction apparatus.

HAEBLER describes his apparatus as follows:

Although for more than 2 years we could do our nailings without any reduction apparatus and without exposing the fracture site we must admit that often, especially in femoral fractures, the operation was very difficult, and we deeply regretted not having a good apparatus to set the fracture. Such apparatuses were repeatedly indicated to us, yet so far we have not succeeded in obtaining any of

them, the HERZOG lever excepted. As simple as the latter in principle may be it did not satisfy us perfectly. Indirectly we learned that also the other apparatuses were anything but up to expectations. This may be taken as an excuse in our explaining why we endeavored to add another to the already existing apparatuses.

The device we had in mind should be easily movable and if possible usable in combination with all the familiar extension devices, thus rendering it employable for all mobile units of an army in the field.

It also was designed to develop great efficiency in power, to keep the position obtained firmly fixed and to be as simple as possible in manipulation, yet without being a hindrance to the X-ray observation and to the surgeon.

We believe that all these demands have been fulfilled with the apparatus as shown below (see illustration 67).

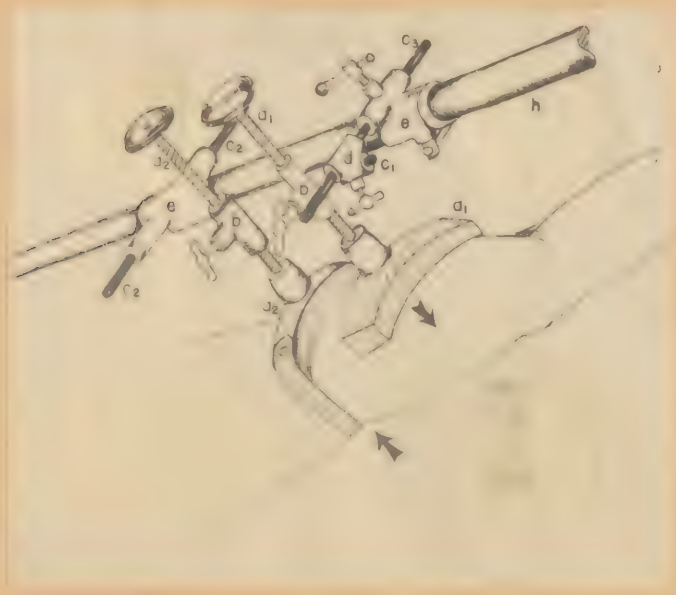


Illustration 67.
HAEBLER reduction apparatus.
a,1 - pressure spindle
a,2 - traction spindle with padded wooden cross-rail,
b - right angle sleeves for male screws
c,1 - right angle sleeves for the male screws
d - right angle sleeves for the cross-bar
c,2/c,3 - tie-rods to the extension rail
e - right angle sleeves for the tie-rods
h - rail of the extension device.

The working mechanism is similar to that of the HERZOG lever.

One (a) of the two male screws with their padded wooden cross-rails acts as a forcing spindle (or hypomochlion) while the other one (a,2) by means of a leather

strap, which likewise is padded, draws the other fragment end nearer. Both spindles, due to the right angle sleeves, can be moved on a cross-bar (c,l) and thus are capable of being brought as near as possible to the fracture site.

This cross-bar (c,l) is connected through two pairs of right angle sleeves with the rail of the extension device (h). In this way a frame with a stable fracture is formed, which through the various right angle sleeves and cross-bars will enable the male screws to move within a semicircle in any direction wanted or enables them to hold the fragments firmly in a given position. Therefore any lateral displacement can be corrected.

The direction in which the apparatus is to operate is determined by fluoroscopic observation: After having extended the limb in such a way as to get the fragment ends in a distracted position, one is to go around the limb medially or laterally with the X-ray tube, until the direction in which the fragment ends are facing each other exactly is determined. Then the tube is exchanged with another one which has a centering rod. This will indicate the direction the male screws have to operate. By fluoroscopic control in the plane which is vertical to that and by screwing the male screws tighter any still existing dislocation can be adjusted.

Since the apparatus will maintain the position when once established one will under certain circumstances be able to work with one X-ray apparatus only. However, after the introduction of the guide rod and the driving in of the nail one never should neglect to ascertain by X-ray control once more whether in fact the fragment ends are duly engaged and the guide rod has entered the distal marrow cavity.

The right angle sleeves fit the extension bars of all the usual extension devices.

Another advantage is that the device can be used also in fractures of the upper part of the femur. Then the spindle sleeves (b) must be fixed to the cross-bar (c,l).

The shadow of the metal bars will not be any hindrance if one will settle on an exact sagittal or frontal fluoroscopic control and if the X-ray units are placed in a corresponding position (perpendicular to each other).

Principally the device is to serve for the fixation of femoral fractures. In leg fractures we ourselves never made use of it, and for the humerus also only rarely. In those instances one can perform the nailing from above in the position I and usually only one of the male screws is needed thereby.

So far the design has served our purpose satisfactorily. Whether or not it will meet with the approval of other people as well, only practice will show. One advantage at least is an established fact: The cost-price is low.

KUNTSCHER reduction apparatus.

The power required to adjust lateral displacement with simultaneous longitudinal pull is rather great and of course it must be stronger as the pull increases. Yet longitudinal traction is absolutely necessary, and even is the most important factor in the reduction because lateral dislocation can never be adjusted until the shortening is overcome. That correlation can easily be derived from the diagram in illustration 68.

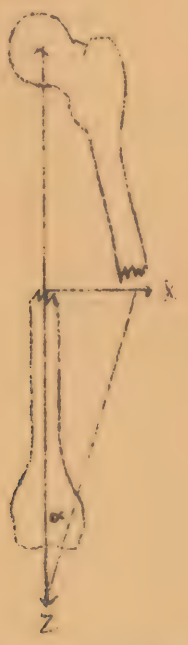


Illustration 68.
Diagram of the forces required for the reduction of a femoral fracture. The longitudinal traction, required to overcome the muscle traction and the reaction of the soft parts is called extension force and is represented by the symbol Z, while the lateral pressure required to balance the lateral displacement is represented by the symbol X; the angle by which the lateral movement is effected shall be alpha.
Then we have the equation: X = Z x tangent alpha.

In a femoral fracture, if f.i. the longitudinal traction amounts to 50 kg., a force of 50 kg. is necessary to bend the distal fragment laterally or medially by an angle of 45°, as tang 45° is equal to 1. This means that the force necessitated to bend the bone is exactly as big as the longitudinal traction. For a bending by 20° only the force required is 18 kg. Therefore one is induced to attempt a diminution of these forces in order to facilitate the reduction. This can be achieved by setting the point of attack for the extension on an equal level with the fracture. Then the component to the traction force required for lateral movement is even equal to zero. It actually no longer exists and only that force is required which is necessary to adjust the position of the soft parts (see illustration 69).

Illustration 69.
Elimination of the lateral component to the longitudinal traction force by shifting the point of attack of that force to the fracture cleft. At any angle of the distal fragment that component force will be equal to zero.

The point of attack of the traction force can be shifted to the fracture cleft if the traction spindle is connected with a ring laid around the extremity along which it can be moved. An uncomplicated device of the author which works according to the same principle is shown in illustration 70.

The patient lies in lateral position, the pelvis is buckled to the extension table by a belt fixing the healthy extremity. The knee of the injured side is flexed to a right angle. The femur is placed in a padded wooden ring which is movable and connected by 3 strong wooden bars with a padded board fixed to the anterior side of the tibia. The patient, so to speak, kneels on this board to which the leg is tightly buckled by two straps. On the medial as well as on the lateral side of the ring a wire cable is fitted. The two cables are attached to both ends of a strong steel-pipe, 2 m in length upon the middle part of which the spindles of the extension device rotate. In the normal rotation position of the knee-joint this pipe is in a perpendicular

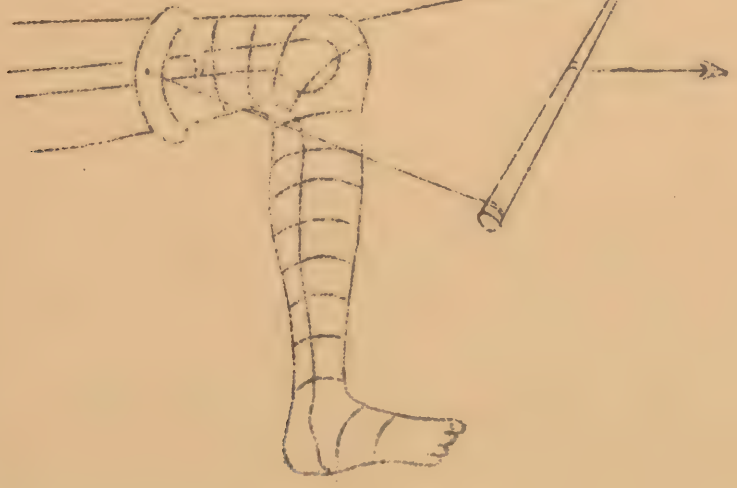


Illustration 70.
Reduction device of KUNTSCHER for the femur working according to the principle of elimination of the lateral component.

position. Under fluoroscopic control the ring is now adjusted until it is on a level with the distal fragment. Then traction is exercised by screwing the spindles of the extension device until the shortening is balanced. Despite strong traction the leg may now be angulated on the fracture site in any direction and also be rotated, the leg acting as a lever arm. In that way, and this is most important, the distal fragment can be carried around the proximal one (setting the limb by circumduction). The leg in its full length is stretched so that it is not in the way.

Other reduction auxiliaries.

As far as the experience of the author goes, only in the reduction of the femur are special reduction apparatuses needed. As concerns the humerus, or the forearm, manual reduction by an assistant surgeon is sufficient, and for the leg traction on the extension table. The well-known simple BOEHLER device with male screws used to apply extension plaster casts to the leg has proved very useful. Only the bars towering up on both sides of the knee-joint constitute a slight obstacle. The lateral dislocations may be eliminated by the application of strong bandages, that are to be pulled in the direction desired by manpower. MAATZ uses pulleys for this purpose, hooked to the wall or the ceiling. In this case the operation table must be secured against dislocation by counter-traction, and a great number of firmly fixed hooks must be available for use.

From the very outset the author has used the marrow nail for reduction. This indeed is a very helpful auxiliary. If the nail has been sufficiently deeply driven in, so that there is no risk of pieces of the bone tube breaking away, then the fragment is as it were firm like a handle in the operator's hand and it can be pressed upon the other fragment. In the case of the femur thus the proximal fragment can be moved. Of course a certain amount of force is to be applied, because the torque of very strong muscles such as the gluteus and the psoas has to be overcome. One must bear in mind that the pivot of these reduction movements depends on the hip joint and that the protruding nail head moves in the opposite direction to the fragment end (see illustration 71).

As soon as the fragments are thus put together, the guide rod is inserted through the marrow nail into the distal fragment and it is completely driven in. Correspondingly the marrow nail serves as a reduction apparatus for other long bones too, usually concurrent with other reduction measures. For fractures in the proximal part of the femur the method is inapplicable, as too much room for moving was left for the marrow nail. Except for marrow nailing of infected fractures for reasons of asepsis the nail must in no case be touched with bare hands, but only with a cloth cover.

Illustration 71.
The marrow nail as a reduction apparatus. The marrow nail has penetrated deep into the proximal part which thus can be readily moved. The motion of the nail head and that of the fragment end are counterwise. This is only a schematic design. In practice the sterile fields must be maintained.

E. X-ray control.

Percutaneous marrow nailing is always done under X-ray control. For the femur and the leg 2 X-ray units are necessary, which are to be placed at the dorsal and medial side, so that an intermittent X-ray control of the two planes is possible. For the humerus and the forearm one apparatus will frequently suffice. The X-ray beam comes from below, i.e. the tube is placed on the floor. The fluoroscopy of the other plane is made by rotating the arm by 90°. It is just the rotation which permits a good and stereoscopic view of the type of dislocation, the shape of the fracture and the position of the marrow nail.

Only easily manageable small X-ray units will be suitable. The very efficient Pohl swan-neck apparatus has proven useful. The same applies to the Siemens X-ray ball and the Koch and Sterzel small sets. Whether or not stereoscopic fluoroscopy is useful for marrow nailing must be determined by practice. The author does not command sufficient personal experience in this respect. A certain number of methods has been developed for stereoscopic roentgenoscopy.

The quality of the stereoscopic picture depends on

1. clearness of contours
2. contrast effect.

In fluoroscopy of the lungs both moments are unsatisfactory so far, so that this method was not generally adopted for this purpose as well as for most of the other purposes in medicine, contrary to roentgenosterophotography in which both requirements are met excellently.

In marrow nailing sufficiently usable results may be obtained in both respects. Especially as to the second factor, because both the nail and the bone yield good contrasts on the screen. NYLANDER and the author intended to institute tests with the Wilska set, which effort however was offset by the demolition of their apparatus owing to the events of war. Simultaneously and quite independently MOEYS undertook marrow nailing with stereoscopic fluoroscopy control in Holland, and according to information communicated by him to the author good results were obtained. It is obvious that the reduction, and the introduction of the guide rod and the marrow nail itself can be greatly facilitated by stereoscopic control, if there is a proper stereoscopic vision.

Manipulating with the X-ray apparatus has to be done with the utmost precaution to avoid radiation injuries to the patient as well as to the surgeon. The tubes must not be too close to the skin of the patient and X-raying must not be continued for too long a time. Experience has shown that fluoroscopy of short duration, not exceeding 1-2, at the utmost 3 seconds is sufficient with some practice. The assistant surgeon attending to the reduction wears leaded rubber gloves and an apron. The operating surgeon will not be within the range of the primary X-ray beam. His hands do not need any protection. For safety's sake he may wear a leaded apron under the gown.

If one keeps strictly to these precautions any danger will be excluded. HAEBLER is of the same opinion. He made adequate measurements and found that with the Siemens ball used at a distance of 1 m the skin erythema dose was reached not sooner than after 12 minutes. This would correspond to 240 - 720 single X-ray exposures. Such a considerable number of exposures however will hardly be necessary even in difficult marrow nailings. Although sometimes nailing 3-4 fractures a day and usually wearing only rubber gloves, HAEBLER did not suffer any injury. None the less he recommends stop-watching the period of exposure and to interrupt the operation if the skin erythema dose is reached.

It is recommendable to operate in a darkened operation room and to content oneself with a dimly lighted operative field. There is no need of bright illumination when the small incision is made. It very rarely occurs that some vessel requires a ligature. In the dark room the operator therefore is slightly adapted and thus he will be able in case of difficulties to cast a look upon the fluoroscopic screen over the shoulders of his assistant. If the room cannot be darkened the assistant carrying through the reduction will have to use a cryptoscope and the operator has to rely entirely on the description given by the assistant. The Heinz BRAUN operating cryptoscope is very well suited. The assistant does not enter the X-ray beam. The set need not be held by hand as its screen is kept in balance by a counter-weight. During the operation and the reduction, observation is possible through a neophan glass without the cryptoscope having to be taken off.

In almost every case of percutaneous marrow nailing the fluoroscopic control is sufficient, and only in exceptional cases X-ray photos are necessary during the intervention. In oblique fractures it is often difficult to recognize in which way the guide rod enters the distal fragment or whether it really enters the marrow cavity. As in the nailing of the neck of the femur, the use of a rapid developer is advisable. BOEHLER recommends the following prescription: If in difficult operations several X-ray pictures have to be taken, the use of a standard developer requires 8-10 minutes for each picture, whereas by using a rapid developer only 2 minutes are required. We are working according to the method prescribed by the firm of Agfa. This is:

Solution I:

½ liter of water
50 grams of brenzcatechin
100 grams of soidum sulfite crystals

Solution II:

½ liter of water
30 grams of a concentrated solution of sodium hydroxide,
50 grams of potassium bromide crystals.

As indicated by photographer ESTER the procedure is as follows: The two solutions are prepared in a boiling waterbath. Shortly before use they are mixed to equal parts, as the prepared developer is not preservable for more than 1 hour. After use the developer has to be discarded. Developing takes about 50-60 seconds. Attention should be paid of not soiling the clothes and the hands, and therefore it is recommendable to hold the film by clamps to spare the skin. After developing, the film should be rinsed in clear water. Then the film is placed for 2 minutes in a fixing solution of the following composition:

Solution:

1 liter of water
300 grams of sodium thiosulfate
30 grams of potassium metabisulfite.

In order to obtain very durable pictures it is advisable to place them after inspection in the fixing solution for another 10 minutes. After that it should be thoroughly rinsed for two hours. One may expose the pictures to daylight after only a half minute stay in the fixing solution but this has the result that stains and also a yellowish haze appear on the pictures and it deteriorates their quality.

F. Asepsis during percutaneous marrow nailing.

Marrow nailing is an intervention on the bone and makes utmost demands on the asepsis because due to its poor vas-

cularization the bone is not sufficiently able to offer resistance against the invasion of germs. As is well known, the requirements for asepsis are much greater than in abdominal surgery. Even though, as stated in the preceding chapter, conditions in marrow nailing are much more favorable than in the usual surgical exposure of the fractures, the operator is by no means relieved of the obligation to apply the same strict principles of asepsis as in bone surgery. This principle is frequently disregarded during marrow nailing. HAEBLER is right in contending that the majority of the infections so far observed in marrow nailing is due to an avoidable negligence in asepsis. It is understandable that this modern and unique method of fracture treatment attracts many spectators interested in the matter. Yet, as all the other people occupied in the room, they should wear caps, masks and sterile gowns. Marrow nailing of a closed fracture is by no means an operation to be shown in a college lecture. If on any part of his body surface the patient suffers from old wounds, furuncles or carbuncles, marrow nailing is not permissible. In case of fresh wounds and burns marrow nailing is permissible except within the first hours after the accident, before infection has developed at the site of the injury and only if its site is not in the neighborhood of the insertion site of the nail. If there are extensive wounds so that complications must be anticipated, marrow nailing is also not indicated. (Marrow nailing of compound or infected fractures see chapter VI).

It stands to reason that the operating theatre and the sterilization apparati have to meet the strictest standard. The skin around the insertion site of the nail requires careful nursing during several days before the operation takes place. For the time being, however, no preparatory treatment with alcohol and a diluted alcoholic solution of iodine and no covering with sterile sheets is possible. The skin is painted with tincture of iodine, and if possible, sterilized flannel is pasted on the wound so that all contact of the skin is impossible. Then the operation area is covered as usual with sterile sheets. It is of advantage to cover the incision site with a sheet with a circular hole, 5 cm in diameter. The flannel is cut with the skin. The instruments must not be touched on the ends introduced into the wounds, neither by the surgeon nor by the nurses. They must only be manipulated on their handles. WATSON-JONES' suggestion is very useful to have the instruments ready on the instrument table and to mark the two parts. For one half of its length the table is white-draped, for the other one blue. The instruments that can be touched by the hands are placed on the white part, those that will come into contact with the wounds on the blue one (see illustration 72).

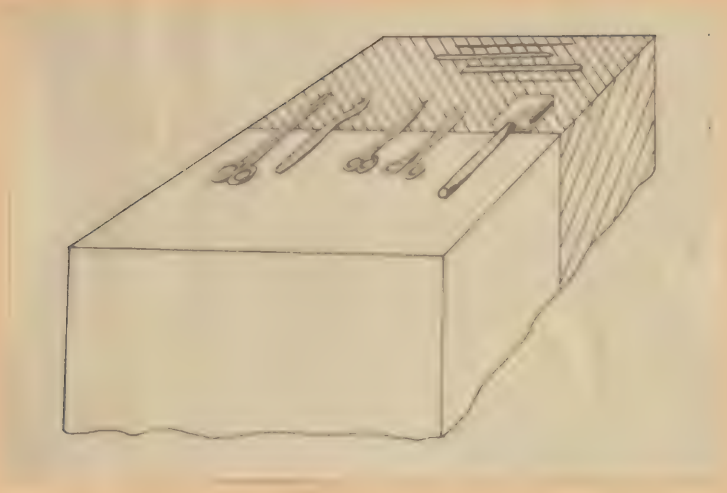


Illustration 72.
Instruments used in percutaneous marrow nailing are ready on the instrument table. The tablecloth is double colored. On the white side are the parts of the instruments that may be touched with the hands, on the dark one are those that will come into contact with the wound.

The nails, of course, are placed within full length on the dark side of the cloth and must not be touched with the hand, but only with instruments or sterile cloths. Wrapping the nail in a cloth while driving it in is of advantage as thus the nail is dirigible. In quite the same manner the guide rod is manipulated. The wound is closed by skin sutures, as there is no need of buried sutures. The needles are threaded by instruments. Knotting is likewise effected without using the bare fingers, as it was described by J. JOSEPH for the skin plastics in which case it was called apodaktyle knotting. The thread is to be handed and knotted only by forceps. As there are only two button sutures to be made, the loss of time is not great. (See illustration 73).

Asepsis is also endangered by the operation taking too much time, because the number of germs settling down on the wound, the instruments and the hands of the surgeon and the nurse steadily increases. Furthermore, long repositioning back and forth motions in the marrow cavity, hammering, etc. constitute increased danger of shock (see chapter IV) so that the operation must be stopped after an hour, the nail pulled out or sawed off (see chapter V), and a plaster cast or traction bandage must be applied.

An advantage in percutaneous marrow nailing is that for the operation itself no assistants are needed, thus reducing the danger of infection.

A considerable hazard for the asepsis lies in careless fluoroscopy by somebody touching the wound or the instruments in the dark. In each of the short X-ray exposures therefore the wound should be draped by a fresh sterile sheet and the table of instruments must be placed in such a manner that nobody can brush it in the dark.

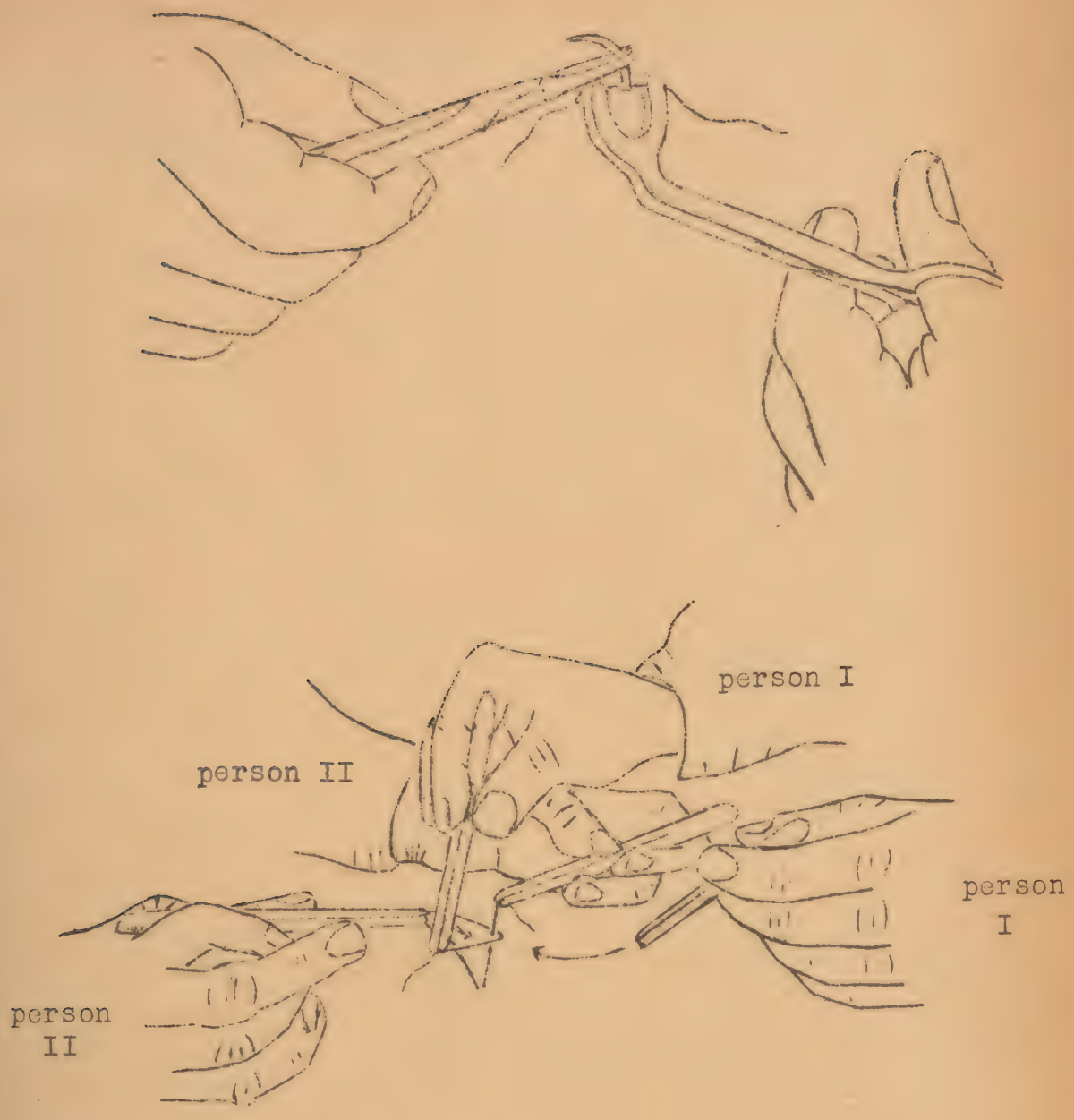


Illustration 73.
Apodaktyle threading and knotting as prescribed for skin sutures by J. JOSEPH.

G. Anesthesia.

It is of primary importance in the reduction process that the musculature be relaxed as far as possible. Plexus anesthesia is best suited for the arm and lumbar anesthesia for the leg. The latter is not advisable in patients under the age of 40 years because of the side effects. They should be given general anesthesia. The author administers evipan/ether, for children chlorethyl/ether. In tibial and humerous marrow nailings, where things usually proceed very quickly, evipan anesthesia will often suffice, which in the case of necessity may be continued with an ether narcosis.

BOEHLER made various marrow nailings under local anesthesia, sometimes adding a little evipan when driving in the nail. Frequently the marrow cavity is completely insensitive as we have come to know from various removals of marrow nails made under local anesthesia. Yet often there are also rather strong dull pains felt inside the bone which will disappear immediately after the nail is removed.

If as a consequence of prolonged reduction the muscles have not been seriously bruised the patients will not have pains afterwards, but they will be free from fracture pains and this is to be attributed to the marrow nailing. This may be explained by the complete elimination of the friction the fragments had exercised upon each other and we know from our daily practice how sensitive the periosteum is to pain. Anesthesias causing prolonged sleep therefore are superfluous and even undesirable as one must aim for an early return of the muscle tonus as for some osteosyntheses this tonus constitutes a component for their stability.

Time and preparation of percutaneous marrow nailing.

Percutaneous marrow nailing should be performed as early as possible because the muscles and soft parts atrophy is increasing with every day of waiting and reduction becomes more difficult. If there is one of the counter-indications,given in chapter IV, as f.i. shock, necessitating postponement, extension treatment has to be applied until the nailing can be undertaken, preferably in the form of wire extension since the strap extension has proven unsatisfactory. The wires can then be used for extension during reduction, and may be removed after marrow nailing.

It did not prove successful to nail on the very day the accident occurred. Some degree of shock is present in all bone fractures and one should wait until it is gone. HAEBLER repeatedly did the nailing the first day, but has abstained since, because the muscular spasm renders the reduction too difficult. For the lower extremity the period between the 3rd and 7th day is probably suited best. During the first 3-4 days the application of extension treatment is not necessary, but immobilization in a VOLKMANN splint will be sufficient. The upper extremity may be nailed on and after the second day. Even after many weeks percutaneous marrow nailing may be successful, if extension treatment was carried through in the meantime. Sometimes reduction is even successful if very slight traces of callus are visible. These, however, are exceptions. In such cases reduction should not be attempted for many hours, but they should be interrupted in time and the nailing renounced. Or, if justified by a special indication, the exposure of the fracture site may be undertaken. (See chapter VI). If an old fracture of the femur with a shortening is to be treated, the extension method is first to be applied for some days. After compensation of the shortening marrow nailing can be done.

X-rays before marrow nailing.

Preliminary measures also include the preparation of good X-rays. They are of special importance because it depends on them whether or not the fracture will be determined as suitable for marrow nailing and which nail should be used.

Choice of the nail.

a. Determination of the thickness of the nail.

The best course is to always make X-rays of all fractures, according to a standard procedure. If it is decided to perform marrow nailing the first X-rays will be sufficient. It is of utmost importance that the fractured bone is shown on both pictures in its full length, and that the pictures are taken at the same distance. If the marrow cavity is not visible to its full extent one cannot detect any narrowing of it. Then marrow nailing will not be a success from the first, as the nail is too large in thickness and it cannot pass the marrow passage in the cavity. If f.i. the fracture is in the lower third of the femur the upper third must always be visible in the X-ray too.

The thickness of the marrow nail is determined by the width of the marrow cavity as shown on the X-ray. It appears on the film as a silhouette of a central projection, and this silhouette is the more magnified the less the distance is between the tube and the film. For that reason the marrow nail must always be choosen thinner than suggested in the X-ray. The most suitable distance between the film and the tube focus is 1 m. Then the oversize of the femur on the X-ray is about 10 %, according to HAEBLER. It means: If after careful measuring the narrowest passage of the marrow cavity has been found to be 10 mm on the picture, the thickness of the nail wanted is 10 mm - $\frac{10\text{ mm}}{10}$ = 9 mm.

The oversize, i.e. the extent by which the picture B exceeds the bone shall be X, the distance between tube and film F, and the distance between bone and film f. Then, according to the principle of the similar triangles the following equation is valid: $X = \frac{f\ B}{F}$

In the middle part of the femur shaft the smallest passage of the marrow cavity is located. The average thickness of the thigh here is about 20 cm. Since the bone is located approximately in the center the distance f between the bone and the film amounts to about 10 cm in both X-rays with the plate holder placed tightly up on the skin. As the distance between tube and film remains constant, namely F = 100 cm, $X = \frac{10 \times B}{100} = \frac{1}{10}$ B. On the lower leg, the humerus and the forearm the distance f amounts only to a few centimeters or even fractions of a centimeter. With these bones the deformation of the shadow is negligible at a distance of 100 cm. and the nail may be laid on the X-ray to

observe whether it coincides exactly with the contours of the most narrow part of the marrow cavity. Only in the case of the femur must the most narrow part of the medullar cavity be exactly measured and the finding evaluated as indicated above.

EHRLICH avoids any calculation by fastening a marrow nail to the skin with adhesive tape at the distance bone - plate holder. The shadow of the nail on the X-ray is deformed on the X-ray photo to the same proportion as that of the marrow cavity. From the X-rays one recognizes whether or not the nail fastened to the leg has the right thickness, or whether a thicker or a thinner nail is to be used. Maintaining a standard distance of the tube is not necessary (see illustration 74).

Illustration 74.
Determination of thickness and length of the nail according to EHRLICH. A nail has been fixed to the skin in the distance bone - plate-holder. On the X-ray its deformation is proportional to that of the marrow cavity.

In taking the pictures stress should be laid upon obtaining really sharp contours and also distinct contrasts. Otherwise the marrow cavity will appear wider than it is in reality and this will lead to the device of too thick a nail. Broadly speaking the general principle should be: Better choose a nail too thin than too thick.

As the marrow cavity shows a slight bending and as a result of the various irregularities and roughness of its wall even a thin nail will effect a sufficiently firm and elastic clamping so that an entirely stable osteosynthesis is formed, provided that the nail is long enough.

b. The correct length of the marrow nail.

The correct length of the marrow nail may vary within a wider range than its thickness, and experience has taught that it is preferable to select a nail somewhat too long than too short. The nail should be inserted for at least 6 cm in both fragments. Sometimes this stretch is even too short, but in fractures of the middle portion of the long bones this requirement can easily be met. It is of no significance if the point of the nail has entered the marrow cavity beyond the fracture cleft not only 8 cm, but even 9 to 10 cm deep. In fractures close to the joints these 2 - 3 cm. may be the cause that the nail point penetrates into the joint unless precaution is taken by constant fluoroscopic control. When calculating the length

of the nail by means of X-rays strict attention should be paid to the fact that the fracture shortens the leg considerably; this condition is thoroughly compensated through the method. Therefore at first the length of the nail has to be determined for one of the fragments and this must be added to the length required for the other fragment. In the case of the femur the deformation of the shadow by the X-ray projection has also to be considered. At a distance of 100 cm. from the tube and a length of the marrow cavity of 40 cm. it amounts to 4 cm. There is a certain additional range for the femur, because the head of the nail may protrude by 4 - 5 cm. from the trochanter without causing any complaints whatsoever. There is even a necessity that the nail extends beyond the tip of the trochanter by at least 1 cm. If the nail is inserted more deeply, its removal may cause considerable difficulties. On all other bones the marrow nail must not project by more than 1 or 2 cm. and it must not be driven in more deeply so that no free play is left. Broadly speaking, the determination of the length of the nail requires less attention than the determination of the thickness of the nail and 1 or 2 cm. usually are of no significance.

The preparation of the marrow nailing furthermore includes the setting up of the extension and reduction appliances and the installation of the X-ray units. For the first marrow nailings it is advisable to rehearse this the day before with someone acting as the patient. Even if the personnel is well trained it is desirable to discuss the position of the patient the evening before and to arrange the apparatuses. Since marrow nailing is an operation of highly aseptic character, it should be at the top of the operation schedule for the following day, this causes no disturbance even in a restricted space, but it rather spares time. The operation is unnecessarily delayed, if one begins not earlier than during narcosis to see to the correct placement of the X-ray equipment, reduction appliances, etc.

Percutaneous Marrow Nailing.

II. Special Part.

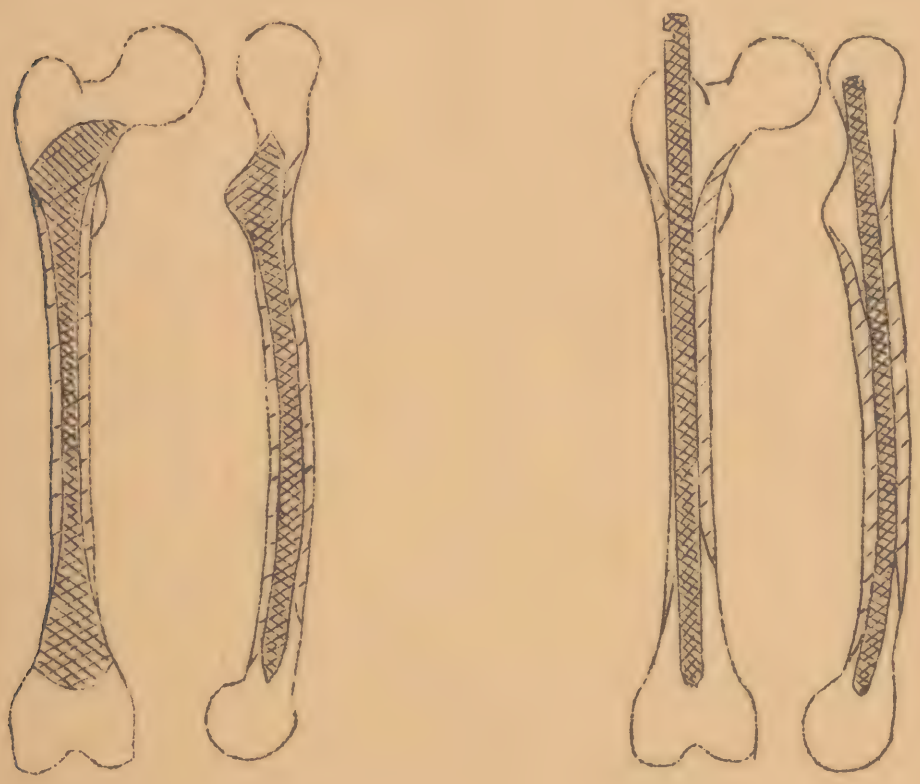
a. Percutaneous marrow nailing of the femur.

1. Shape of the marrow cavity and of the marrow nail.

The marrow cavity of the femur is a cylindrical tube which throughout its middle portion is fairly constant in width. Proximally and distally the tube is conically widened. Its most narrow part, which is decisive for the thickness of the nail, lies slightly above the middle of the femur. Here the compacta has its greatest thickness. At its distal end the marrow cavity is considerably widened and filled with wide-meshed spongiosa which increases in density towards the joints. In the anterior view the marrow cavity tube appears practically straight. Laterally

it shows a slight bending with the convexity towards the front. The marrow nail has to adapt to this bending when it enters deeper into the marrow cavity. For this purpose part of the energy expended on driving the nail in is used. This bending provokes a stable osteosynthesis, even though the marrow nail is too thin.

BOEHLER has investigated the form of the marrow cavity of the various bones and their varieties. At his suggestion EHRMANN made impressive X-ray pictures of marrow cavities by filling them with barium medium. (See illustration 75).



a b

Illustration 75.
Marrow cavity of the femur.
a) Marrow cavity filled with barium medium (EHRMANN).
b) Femur with the marrow nail driven in.

Marrow nailing of the femur is done with a straight, rigid nail. Its cross-section is V-shaped (see illustration 76). When it is driven in vigorously the arms of the V approach each other in a very small measure as a result of pressing the nail into the marrow cavity. E. POHL has increased the stability of the nail considerably by barel - ing and bending the arms of the V. In order to improve its springiness the nail has been made on its back-side of somewhat thinner plate material. Nails for the femur are manufactured in lengths as follows: 30, 34, 36, 38 and 40 and 42 cm. In arthrodesis of the knee-joint marrow nails 65 and 70 cm. in length are used (see chapter VIII).

The thickness of the nails required is 8, 9, 10 and 11 mm. The usual sizes are 8 to 10 mm. It is surprising that the marrow cavity does not show a wider variety of width, although development of the muscles and length of the bones vary considerably. There are, however, exceptions. Frequently one is struck by the width of the tube with very old pseudarthroses. Extra sizes of 11 - 18 mm are incidentally needed. They may be made of thinner sheet metal and thus their transverse springiness is increased. It rarely occurs that the most narrow passage of the marrow cavity in femurs of adults is less than 8 mm. In such cases it is not advisable to use marrow nails of 7 or even 6 mm in width, because they are not sufficiently stable to resist the powerful muscle traction in adults and consequently are liable to be bent. It will be better to widen the marrow passage of the cavity to 8 mm with POHL's marrow drill (see Part I of this chapter).

The dimensions of the femur marrow nails for children are:

length: 24, 26, 28, 30 and 32 cm.
thickness: 6 and 7 mm.

In infants round solid steel rods 3 mm in diameter are used, with the points flattened. They are cut in lengths according to need.

The head of the nail bears an eye. Its length of 10 mm permits the insertion of extremely strong hooks, so that the removal of the nail can be effected with great vigor without risking that the hooks break off.

The point of the nail is slightly conical and the edges are rounded. Towards the point the metal sheet gradually becomes thinner, but the edges are not so sharp that they cut nerves or vessels. The latter will give way. Yet if there is no such possibility of giving way, as f. i. with soft parts squeezed in between both fragments the vessels and the nerves are severed.

In the early stage of marrow nailing the marrow nail was given a slightly conical form in order to facilitate its removal. From head to point it gradually tapers off to a really insignificant degree. This tapering was so small that it could be ascertained only by measuring instruments. Experience has shown that this measure was not necessary so that the nails in use now are constant in width throughout all their lengths, the points excepted. (See illustration 76).

a b c

Illustration 76.
Marrow nail for the femur.
a) head, b) point, c) cross section

2. Proper placing of the patient in marrow nailing of the femur.

The author made his first marrow nailings of the femur in the same position as it was prescribed by SVEN JOHANNSON for the extraarticular nailing of the neck of the femur. In dorsal position with traction applied to both legs, the hip joints extended. The injured extremity is not abducted but adducted. The sound leg is however all the more abducted. As it became evident that the soft parts of the loins disturbed the introduction of the nail, the author made the attempt to perform marrow nailing in a lateral position with the hips flexed. The advantages of this method are great. The nail can be driven in without the slightest disturbance because the surgeon can do his work quite unhindered and freely. Should the exposure of the fracture site become necessary, the incision can be made laterally which is most favorable because here the bone is nearest to the skin and only a thin layer of muscles has to be cut through (see chapter VI). Moreover, no important vessels or nerves are situated on the lateral aspect. However, a small number of authors, such as HAEBLER, use the dorsal position in cases where it is clear from the very beginning that the reduction will not be easy, as they believe that reduction in lateral position might be more difficult. Although the author cannot agree with that view a description of the dorsal position is given herewith.

In marrow nailing of the femur in lateral position the patient is placed on his healthy side. The pelvis support of the extension table is turned sidewards and the femur of the healthy leg with the trochanter rests on it. The post of the pelvis support fits the joints and the symphysis, thus the frontal plane of the pelvis is exactly vertical. The patient is placed on the extension table with the hips slightly flexed. The left leg is buckled to the right-hand bar, and the right leg to the left-hand bar. Now, the bar with the injured leg is abducted until the hip is flexed at an angle of about 45 - 60°. The sound leg is flexed at about 20°. If the bars of the extension table cannot be abducted beyond the middle line the sound leg has to remain in a straight position. Similarly as in nailings of the neck of the femur a well padded strap is placed between the legs. It rests on the shaft of the healthy leg and is fixed to the edge of the table near the head (see illustration 77). Care must be taken that there is no squeezing of the genitals by the strap.

Then the X-ray units are brought into position. One apparatus is placed so that the beam is directed upwards. Since the hip of the injured leg is flexed more than that of the sound one the latter will not be in the way when X-raying from below. The other X-ray unit is placed on the same level with the fractured femur and is directed towards the frontal plane. It can be moved or rotated to fluoroscope also the trochanter area. It will be of advantage if the assistant surgeon who manipulates the X-raying and the reduction is able to serve both apparatuses from one place, and to switch the room illumination on and off. Then one of the reduction apparatuses is put up and a

powerful pull is exercised by turning the extension spindles. Now the assistant surgeon starts with his reduction attempts. Should he succeed in uniting the fragment ends well, or if this is achieved only temporarily, or if he can approximate them to a point which makes it likely that after the introduction of the nail the latter can be used as a reduction handle to make the union a definite one, the nailing can be undertaken. Otherwise a traction or plaster cast has to be applied, or if particular circumstances demand it (see chapter VI), the fracture site must be exposed and open marrow nailing be effected. In such a case the position of the patient remains as it is and the operation can be started at once.

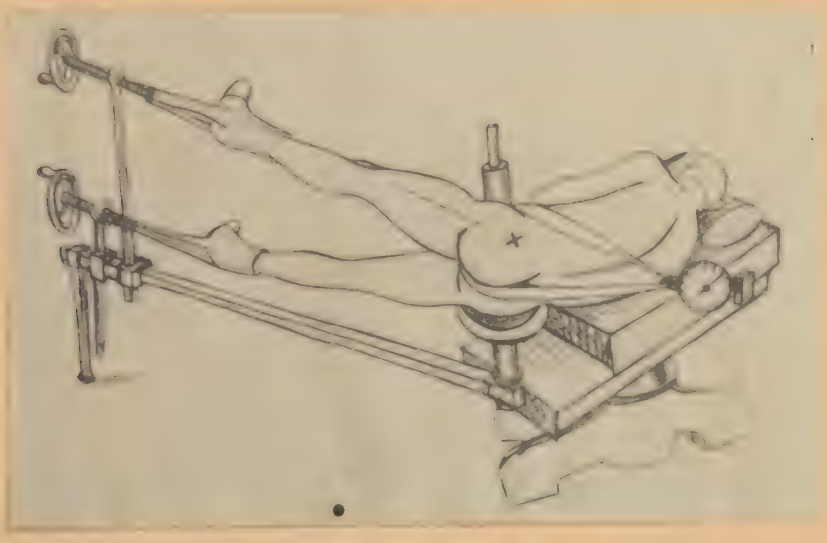


Illustration 77.
Lateral position in marrow nailing of the femur. The patient lies on the well side. Placement of the patient includes also protecting him from catching cold on the extension table by wrapping him up in blankets or sterile sheets.

If percutaneous marrow nailing is possible the assistant surgeon, under fluoroscopic control in both planes, places the edge of an iron ruler or strong square iron stick on the frontal and on the lateral surface of the femur, longitudinal to the center of the marrow cavity. After switching on the illumination of the room he draws a line out on the skin as indicated by the edge of the ruler. Both lines then must be elongated distally from the tip of the trochanter to their point of intersection (see illustration 78).

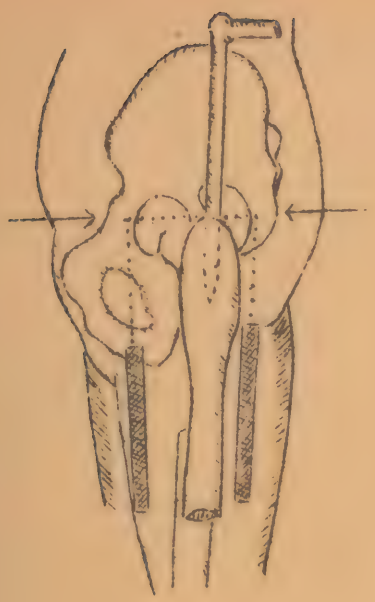


Illustration 78.
The direction of the marrow cavity is marked on the skin in both planes.

If the leg is rotated after the marking, the indicated location of the tip of the trochanter is no longer correct. The direction of the marrow cavity naturally remains the same. If the hip is flexed the tip of the trochanter is also easily found by palpation. At the intersection point of the marking lines an incision of 1½ to 2 cm. in length is now made in the skin, which runs longitudinally to the line of the femur. Depending on the thickness of the skin and the fat layer beyond the trochanter area that point is about 4 - 7 cm. above the tip of the trochanter (see illustration 80).

3. Driving the marrow nail of the femur home.

The trochanter region is painted with iodine and draped with sterile sheets. The markings are copied on the sheets with iodine. The site is then draped with another sheet with a circular hole of 5 cm diameter. The center of the sheet is about 5 - 6 cm. distal from the tip of the trochanter at the intersection of the dotted lines. Care must be taken that the rotation of the leg is not subjected to any change until the trochanter is drilled. If rotated inwards, the tip of the trochanter moves forward below the skin and if rotated outwards it moves in the opposite, the dorsal direction (see Illustration 79).

Illustration 79.
Wandering of the tip of the trochanter below the skin if the leg is rotated in - or outwards. The trochanter is marked on the skin in both cases.

Since the skin is very mobile in this region a few centimeters error won't matter.

Illustration 80.
Place of the incision in relation to the tip of the trochanter.

Then the surgeon takes the guide rod. For thin marrow nails these rods are 4 mm thick, and for thick ones 6 mm. They are 45 cm. long and have a handle bent at right angles. They are made of the best tungsten steel and are pointed. The guide rod is introduced into the wound and the surgeon locates the tip of the trochanter by palpation. Then the point of the guide rod is placed firmly on the bone and the direction the rod is to take is fixed in both planes according to the marked lines. It therefore points exactly towards the center of the knee-joint. The surgeon has the knee-joint before him and therefore can aim at this target. By a slight hammer-stroke the thin layer of the corticalis at the tip of the trochanter is pierced, and, while maintaining its direction the guide rod is then advanced by hand, which renders some forceful efforts necessary. After advancing for 10 - 15 cm. into the marrow cavity the assisting surgeon must make sure by fluoroscopy in both planes, whether or not the guide rod lies really in the marrow cavity. After few marrow nailing operations this fluoroscopy is required only for checking, because one aquires the sense of feeling which reveals whether the guide rod advances within the marrow cavity or without. The point of the guide rod glides over the rough parts of the wall of the marrow cavity, creating a continuous resistance. Overcoming the various small prominences is felt in the hand as a shock. If the guide rod perforates it has at first to overcome the strong resistance of the corticalis of the trochanter mass with a jerk and then it glides ahead without any noticeable resistance. The point of the guide rod is not so sharp as to hurt vessels or nerves and therefore no report of any such occurrence has ever been made. In certain oblique fractures the position of the guide rod cannot be exactly made out by fluoroscopic control. In such relatively rare cases one must take X-ray pictures. If fluoroscopy reveals that the guide rod is somewhere located outside the marrow cavity, it must be retracted, pushed forward again in the correct direction and another fluoroscopy must be made. Skilled hands will succeed in introducing the guide rod correctly almost always at the first attempt. Therefore it is not necessary to construct a sighting mechanism. Conditions are much more favorable than in marrow nailing of the neck of the femur. As mentioned above, the marrow cavity widens proximally like a funnel (2 - 3 cm).. The place towards which the guide rod is to be directed is distinctly visible, it is the knee-joint. The marking lines on the skin will serve as an aid. Furthermore, the guide rod is flexible and springy and will follow the course of the marrow cavity even if it is not introduced quite in the exact direction (see illustration 81).

Illustration 81.
The guide rod has been introduced in various directions. None the less, due to its flexibility it follows the course of the marrow cavity.

In his first marrow nailings of the femur the author exposed the tip of the trochanter. Yet, after proceeding in this way only a few times he changed over to making the described stab incision and still uses it because without any doubt in a smaller operation wound the danger of infection is considerably lower. Then no buried sutures, ligations, etc. are necessary. However, some of the authors prefer the exposure contending that the stab incision method is of no particular advantage as regards asepsis, whereas with exposure one can see exactly the spot where the guide rod is to be introduced. The tip of the trochanter is exposed by a skin incision starting from the tip and in the musculature is dissected. The incision runs longitudinal to the thigh. If the fluoroscope shows the position of the guide rod in the marrow cavity to be quite correct, the awl described in chapter IV is put on the guide rod and so the hole at the tip of the trochanter is widened. This is done first to prevent the increase of the pressure inside the marrow cavity and secondly in order to open a straight course for the marrow nail. As demonstrated in illustration 85, the guide rod takes an eccentric way which is of no significance since the guide rod is elastic. But the inflexible marrow nail jams at the tip of the trochanter when it is driven in. Under heavy hitting the spongy bone tissue of the trochanter gives way and the nail is slightly bent. The nailing will be a success after all, but only after considerable efforts. Anyway, widening the hole at the tip of the trochanter will facilitate matters considerably (see illustration 82).

Now, the marrow nail chosen in the appropriate thickness and length before the operation is slipped over the handle of the guide rod. The position of the handle indicates the location of the slit of the nail. For that reason shortly before the nail is slipped over the handle the latter must be turned into the direction desired. Normally the position of the slit is of no consequence. In rare cases of oblique fractures however, jamming of the nail may result. The guide rod never lies exactly in the center of the marrow cavity, as it occupies only a small fraction of its lumen. If in the distal fragment it is pressed towards the compacta the nail's point may be wedged

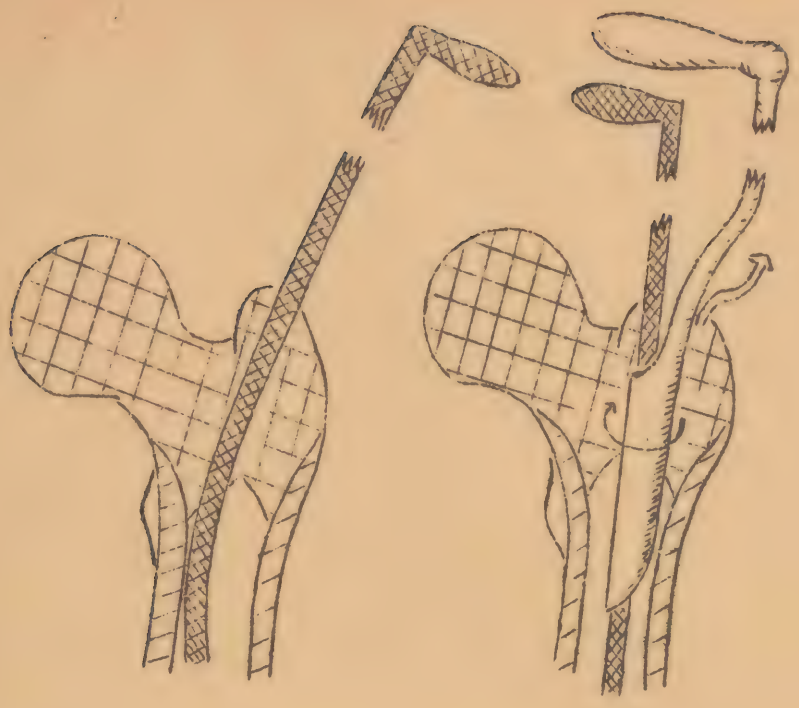
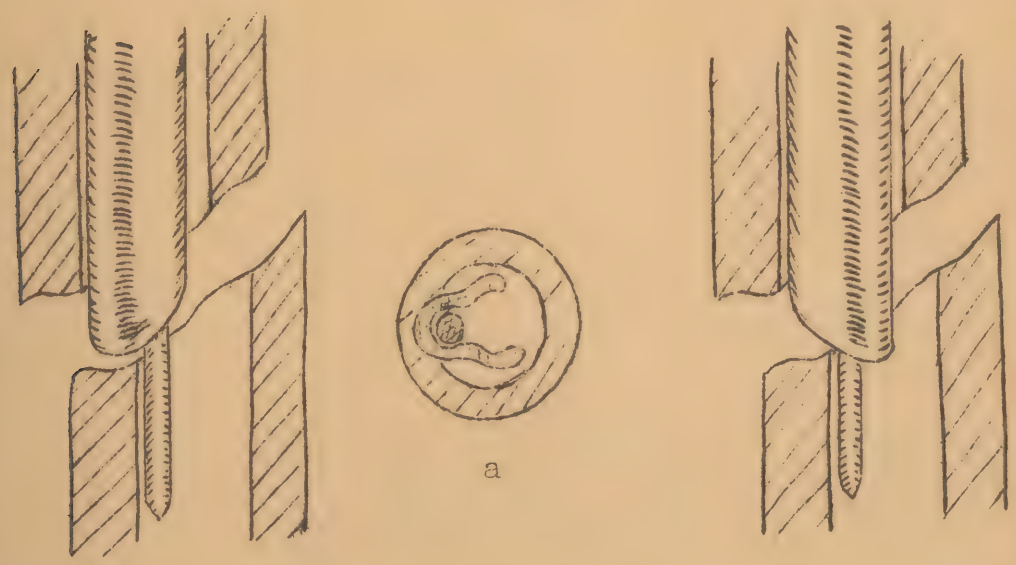


Illustration 82.
The tip of the trochanter is opened by an awl. Thus a straight course for the marrow nail is opened and increase of the pressure inside the marrow cavity prevented.

in the compacta if the nail's slit is turned to the side towards which the distal fragment is dislocated, especially if the guide rod is somewhat too thin. The compacta then forms a wedge between the nail's point and the guide rod (see illustration 83 a).



a Illustration 83. b
a) Jamming of the point of the nail and the guide rod if the nail's slit is turned to the side towards which the distal fragment is dislocated. In order to avoid this incident, the nail must be introduced so that the slit is turned away from that side towards which the distal fragment is dislocated as in (b).

If the hammering is continued the point of the nail cannot advance farther, but instead the nail is jammed more firmly. So firmly in fact that neither the guide rod nor the nail can be removed again. In order to avoid that incident the edge of the nail must be turned so that it points in that direction to which the distal fragment is shifted. Then the nail will automatically glide into the distal fragment. (See illustration 83b).

When the marrow nail is driven in its advance is fairly easy along the first 4 - 5 cm, as it has only to penetrate the meshwork of the spongiosa. Then the resistance of the tubular marrow becomes noticeable. Even heavy hammer strokes push the nail forward for ½ - 1 cm only. If the most narrow passage just above the middle portion of the bone has been overcome, the nail proceeds somewhat more easily. Experience develops a very good feel for this procedure of hammering, and one can judge exactly as to whether or not the nail size was chosen appropriately. If the nail proceeds too easily, so that it advances by about 2 cm. under vigorous strokes, it is somewhat too thin. Yet in this case things may be left as they are, since it was explained earlier that nails too thin in width are better than too thick ones. If, however, the feeling prevails that the nail is stuck and even under heavy hammering advances little or not at all, the hammering must be stopped, as then the marrow nail is too thick. By continued hammering for a long time it may be jammed so firmly within the marrow cavity that its removal is impossible or at least extremely laborious. It is better to remove the marrow nail, which will always be possible relatively easily if the jamming has been observed in time. The guide rod should remain in the marrow cavity and care must be taken that it is not driven out together with the nail. A slightly thinner nail is then driven in over the guide rod. When the point of the nail enters the distal fragment, again a somewhat increased resistance may be felt. Sometimes one feels distinctly when the marrow nail strikes the distal compacta and it gives a peculiar resonance as from a box. Generally speaking, experienced surgeons recognize from the sound of the hammer strokes whether the marrow nail is about to jam in the marrow cavity which is too narrow. The sound grows higher and higher in tone in that case. One also can recognize whether the marrow nail advances well and whether it has already entered the distal fragment or whether it has penetrated deeply into it. At first the marrow nail is pushed forward so far as to be about 1 - 2 cm. from the fracture cleft. The point of the guide rod is also on about the same level.

HAEBLER suggests that while driving in the marrow nail, the guide rod be pulled out repeatedly and re-introduced anew in order to prevent any overpressure in the marrow cavity. This measure is not absolutely necessary if the hole at the tip of the trochanter has been widened with the awl (illustration 86), and dug deeply into the trochanter mass. Now the reduction is repeated. Strong traction is exercised until the shortening is compensated. While waiting a little during strong traction the extended muscles often relax slightly and gradually. Unless the fracture site is located too

proximally, so that the nail has no firm hold here, the surgeon may assist the reduction by using the marrow nail as a handle. The operating surgeon with full vigor presses the marrow nail projecting from the wound and wrapped in a cloth in the desired direction. Frequently it is really astonishing how easily lateral displacement can be corrected in this way. Sometimes after fruitless efforts the reduction succeeds if one slackens the traction considerably and at first corrects the lateral displacement as far as possible and then re-applies strong traction.

It must be emphasized once more that after about one hour of efforts the intervention must be interrupted to avoid the risk of shock. Guide rod and nail have to be withdrawn, the wound sutured and extension treatment applied. Once it has been ascertained by fluoroscopic control that the marrow cavities are approximately facing each other, the guide rod is driven forward another 3 - 4 cm. It can be felt immediately when the guide rod reaches the solid corticalis of the distal fragment. Then the guide rod should be retracted and pushed forward again. After several attempts one will usually succeed in passing the corticalis. Otherwise the lateral displacement of the fragments must be corrected. If fluoroscopic control shows the point of the guide rod alongside the distal fragment the guide rod must be withdrawn; the fluoroscope will indicate in which direction the reduction must be improved. If, however, it is revealed that the guide rod lies within the distal marrow cavity, success is achieved. Reduction is now fully secured. For safety's sake the guide rod is advanced another 5 - 6 cm. It is true, the guide rod may bend. For a recurrence of the lateral displacement the guide rod would have to be sheared off. And for that purpose forces amounting to several hundred kilograms would be necessary, which can by no means occur here. During the war the guide rods had to be manufactured temporarily from less resistant material. STOEHR has reported a case where the point of a guide rod broke off. With the recently manufactured guide rods such an incident cannot occur. The guide rod should project by 6 - 8 cm. into the distal bone tube. Of course care has to be taken not to introduce the guide rod so deeply as to penetrate into the knee-joint. By means of another guide rod one can measure without any difficulty how far the point has advanced. This will save the trouble of changing the position of the X-ray tubes focussed to the cleft of the fracture. The second guide rod is taken by its tip and held to the handle of the inserted guide rod. Holding it in the same direction its handle indicates where the tip of the marrow nail inside the cavity lies. (See illustration 84).

During this determination the guide rod used for this purpose is outside the aseptic area and it must be laid aside immediately. Hence it is of importance to always have several guide rods available. This procedure is also appropriate to locate the actual position of the nail tip by holding a nail of the same length above the operation area. This is however applicable to a minor degree in percutaneous marrow nailing than in the marrow nailing osteotomy, in which case no fluoroscopy is used.

Now the nail is driven forward. The introduction of the marrow nail into the distal fragment has to be checked by short fluoroscopic control. Thus the jamming of the guide rod and marrow nail as described before in oblique fractures will be discovered in time. In very rare cases it may happen that a small bone splinter jammes in the slit of the nail and thus makes the entry of the nail into the marrow cavity impossible. In most cases however, the introduction can be performed without difficulty. The initial resistance vanishes quickly with the next few hammer blows because the marrow nail adjusts the distal bone tube exactly according to its own direction and hence it paves its way. Further advance of the nail will progress with the same resistance as encountered heretofore. After the marrow nail had advanced 4 - 5 cm. or so beyond the most distal spot of the line of the fracture, the guide rod is removed. In an oblique fracture with a very steep fracture line the nail will then extend very much deeper into the distal fragment because the most distal point of the fracture plane is separated by several centimeters of free space from the most proximal part of the distal fragment. In proximal fractures the head of the marrow nail is on the same level with the handle of the guide rod, before this depth is attained. If driving in is continued the marrow nail and the guide rod would be driven ahead simultaneously and thus endanger the knee-joint with the guide rod. Instead, the marrow nail alone is driven forward. It is done in the most simple way by using a sawed off femoral marrow nail as a ram (see illustration 85).

Illustration 84.
Determination of the position of the guide rod in the marrow cavity by means of another guide rod.

With that ram the marrow nail is driven only to a depth of 4 or 5 cm., as described before. Then the guide rod is also removed. The extension is released by loosening the spindles so that the leg is now loose in the straps. The fragments are then impacted by having the assistant surgeon strike against the sole of the foot with his fist.

Thereupon the marrow nail is driven in further with the hammer under observation with the fluoroscope whereby care is taken that the nail tip does not endanger the

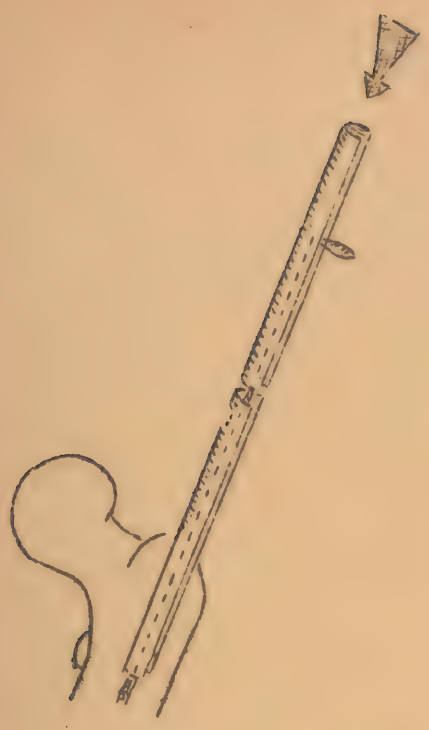


Illustration 85.
To drive the head of the marrow nail forward beyond the handle of the guide rod, a sawed off marrow nail is used.

knee joint. It is driven in until the head is within ½ - 1 cm. from the surface of the skin. Then the marrow nail is driven forward still further with the ram mentioned before, which is furnished with a mandrel or groove, until the head disappeared under the skin and extends beyond the tip of the trochanter by about 1 - 4 cm. By no means should it be driven deeper, as otherwise its removal would cause difficulties. (It will be at least 8 cm. deep in the distal fragment). Examining the distance it is below the level of the skin is most simply done with the ram. Without retracting the latter from the wound it is lifted off the head of the nail and advanced along the head of the nail until contacting the bone. This slightly rough estimate is quite sufficient, as it is the rule: Rather let the nail extend a little too far beyond the bone than to drive it home too deeply! (See illustration 86).

Now another short X-ray inspection is made which in more distal fractures also is to find out whether or not the point of the nail is too close to the cleft of the knee-joint. It should be at least 1 cm. from the cleft of the joint.

Then the wound of the skin is closed by two sutures or clamps. The wound is sealed by a bandage held in place with Mastisol, or some other dressing material. Thus the operation is finished and the patient is put to bed. Here once again it is examined to verify whether or not the rotation position is correct and the osteosynthesis reliably stable.

Illustration 86.
The punch is used to sound the distance by which the marrow nail extends over the tip of the trochanter.

In most cases not even the slightest loosening or dislocation is noticeable. The signs indicating the fracture have completely disappeared. Any supplementary splint or extension bandage is entirely superfluous, rather detrimental.

In the more distal transverse fractures slight wabbling may be observable as long as anesthesia persists and the muscular system is relaxed. It is due to the marrow nail having some free play in the distal marrow cavity.

With the muscle tonus returning this motion usually disappears because the muscles are then predominant on one side. A supplementary fixation bandage is also not necessary, more so as the excursions are only slight. In supracondylar fractures and those mentioned previously as less suitable on account of their shape, a supplementary plaster cast or splint has to be applied. These are made in conformity with the principles and rules commonly used. Although ordinarily these casts or bandages may be removed much earlier, than without using marrow nails, this method can never be considered an ideal one but only as some sort of emergency solution which should be avoided whenever possible. It should be used only where really no other course is possible, as in supracondylar fractures for instance. There, as is well known, it is frequently impossible to remove posterior angulation of the distal fragment in a satisfactory way despite all efforts, because of the excessive pull by the flexors. However with the marrow nail it is possible without any difficulty.

Lateral angulation cannot be prevented by the marrow nail. But it can be corrected by a plaster cast or an extension bandage as the long lever arm of the leg will give sufficient support to the leg. In this case the marrow nail combined with a plaster or traction cast will be a useful solution. In most of the cases of fractures less suitable for marrow nailing a conservative point of view should be observed as far as possible.

4. Further course.

For those treating a great many fractures it is always an event of significance to see the patients able to move the injured limb a few hours after the marrow nailing has been done. The fracture pain is gone and the limb is is firm again. The author noticed even that children who in the morning had been nailed on account of a fracture of the femur, played in the afternoon without beeing embarrassed in any way, and where running about. On the other hand it occurs often that patients in spite of an absolutely stable osteosynthesis are unable even after 10 - 14 days to be ambulatory without suffering pains. These are cases where extensive injuries to soft parts are simultaneously present. It must be well considered that a force so strong as to break a bone certainly will be able to do much more harm to soft parts and in particular to contuse the muscles. In the indirect fracture mechanism there is commonly no contusion. For instance if the fracture of the femur was due to a ski getting into the tracks of carriage wheels. But in the direct mechanism such side-effects of the fracture are more frequent, as f.i. with the shearing mechanism de-

veloping when being run over. This contusion of the muscles and other incidental injuries are hardly noticed during treatment with the plaster cast. But they appear all the more in marrow nailing, where they can be observed and, if necessary, treated. Even if this contusion is of a large extent in simple fractures of the femur one can regularly observe that within a few hours after the operation the patients take the usual lateral position in their beds, not only on the sound, but also on the affected side, that they are able to flex their hips and knees and to sit up. The majority is able to get up the following day. However, only old people who are threatened by pneumonia should be urged to get up so soon. Younger people should first perform the active exercises in bed. This author agrees fully with BOEHLER that in the treatment of fractures under no circumstances should exercises be allowed which cause pains. Besides, only active exercises should be made. Massage is absolutely superfluous, and it even is harmful, as BOEHLER has shown in one case. After some days the patient himself wishes to get out of bed. HAEBLER allows the patients to do so, if they are able to push vigorously with the foot on a box placed at the lower end of the bed. On an average patients will get up 5 - 7 days after the operation (see chapter II). Most patients will put weight on the leg immediately, while others are more cautious. In imperfectly stable osteosyntheses of less suitable fractures a period of 4 - 5 weeks or even more should go before the patients are permitted to get up. It depends entirely on the individual case. In most cases, however, very early motion of the limb will be possible. These cases require continuous supervision to prevent any dislocation with rotation anteriorly or posteriorly. The healing of the stab incision should be carefully watched. If it is infected the sutures will have to be removed and the margins of the wound separated. If the vicinity of the wound is reddened, the temperature slightly raised and one is in doubt whether or not the wound is infected, it is better to have it opened unnecessarily rather than too late. If the wound has been opened in time the incident will be of no consequence whatever. It will heal again within a few days. As long as suppuration persists, confinement to bed is necessary.

If the fracture is found to be infected an incision 10 - 12 cm. in length has to be made immediately on the outside of the thigh by which the fracture site is exposed and the focus of inflammation widely opened. Simultaneously the stab incision at the insertion spot must be extended to a length of about 6 cm. and the head of the nail exposed. Practically in all such cases an abscess is found at the nail's head. The wounds must be kept open by drains and tampons. Further procedure and treatment are exactly as in a nailed infected fracture, as is described in chapter VII. At this point it should only be stressed, that under all circumstances the marrow nail must be left where it is, and that it is to be regarded as a serious mistake, if the nail is removed because of infection. A special treatment or position is not necessary, and therefore nursing is considerably facilitated. As soon as the patient is able to walk without canes he can be dismissed from the hospital. On an average this will be possible 8 - 10 days after getting up for the

first time. HAEBLER permits his patients to take up their duties a fortnight after having been dismissed in order to avoid the feeling of being chronically ill. They should have the feeling of security. In regular intervals of 4 - 6 weeks they are called in for re-examination. After ½ to 3/4 of a year the patient is hospitalized again for another 5 to 7 days to remove the nail (see chapter V).

5. Hazard and mistakes in percutaneous marrow nailing of the femur.

Although in the discussion to this point attention has already been directed to avoiding the most important mistakes and hazards they may be summarized shortly once again:

1. Marrow nailing should not be commenced without having the entire set of instruments within reach. It is particularly essential to have a sufficient selection of femur nails. The appliance for removing the nail is also important. These instruments must be procured.

2. No marrow nailing without having sufficient knowledge of the method. The operating surgeon should have informed himself by means of a book on the details of the technique to be applied and the possible mistakes. Still much more useful is to undergo practical training in a hospital known for practising the method frequently.

3. No marrow nailing with an insufficient asepsis. Here the strictest accuracy is indispensable, as required for any other bone surgery.

4. No marrow nailing of absolutely unsuitable fractures, such as oblique fractures of the distal end which also involve the joint. The decision whether or not a fracture is suitable for marrow nailing in doubtful cases frequently requires much technical knowledge. First it will be advisable to nail only very suitable fractures of the shaft, such as ordinary transverse fractures.

5. Do not fail to take good X-ray pictures. These have to be made at the exactly established distance and should show the marrow cavity in its entire length in both planes.

6. Do not overlook choosing the nails in the appropriate thickness and length the day before the operation. The size of the nails must be determined exactly in conformity with the X-ray findings.

7. Do not fail to compare whether the guide rod fits the chosen nail. The guide rods vary in width in accordance with the marrow nails.

8. Do not marrow nail in shock; fatal issue may be the result. Delay nailing until the symptoms of shock are gone.

9. Do not marrow nail if furunculosis, carbunculosis, abscesses or skin wounds more than 6 - 8 hours old are found. Delay nailing until the abscesses etc. are healed. Then a safety period of a few weeks should be allowed. Quite the same applies to wounds unless it will be possible to do the nailing a few hours after the accident, and still be within the 6-8 hour limit. In such case no regard need be taken even of the muscle stupor.

10. Do not marrow nail if there is a large swelling on the body, or fever. If a large hematoma extends to the place of insertion of the nail the operation has to be put off as there is danger of infection. Also in the presence of fever the nailing should be deferred.

11. Do not introduce the guide rod before the reduction is completed accurately. Before the proper marrow nailing is done, make sure whether reduction is really possible or not.

12. Do not start marrow nailing if reduction attempts made it evident that with the available implements no reduction is possible. If the fragments cannot be approximated essentially, especially in old fractures, there is no hope of achieving this by using the marrow nail as a reduction implement. Closed marrow nailing is not possible in this case.

13. Do not overlook giving the patient protection from cold while on the extension table. On the extension table the patient is particularly exposed to the hazard of cold through chilling and he must be well protected.

14. Do not continue reduction attempts and nailing over more than one hour. By "wrestling" with the thigh and hammering for many hours, driving the nail forward and pulling it back the danger of shock will be imminent. The operation must be stopped in time by extracting the nail or sawing it off.

15. Do not continue to strike upon the nail when it does not go ahead any longer. The nail is either too thick or it got jammed between the guide rod and the edge of the compacta. Carrying on with hammering will result in nothing else but increasing the wedging still further. The nail must be pulled out and perhaps substituted by a thinner nail, or the wedging is to be overcome by correcting the reduction or by giving the nail a turn with the slant of its end along the line of dislocation of the distal fragment.

16. Do not injure the knee-joint with the guide rod or marrow nail. In distal fractures the position of the

point of the guide rod and that of the marrow nail will have to be checked carefully.

17. Do not introduce the marrow nail unless the guide rod has been located within the marrow cavity of the proximal or distal fragment. Make absolutely sure by exact fluoroscopic observation that the guide rod is really within the bone tube.

18. Do not neglect the control of the rotation position, it needs careful watching.

19. Do not fail to take X-ray precautions. The tubes have to be provided with aluminum filters and must not be placed too close to the skin of the patient. Only short exposures ought to be made. Operator and assistant must wear lead aprons, the assistant rubber gloves in addition.

20. Do not drive the marrow nail too deep. It must extend beyond the tip of the trochanter by at least 1 cm.

21. Do not fail to check the stability of the osteosynthesis after the marrow nailing is finished. If there is much motion it is due either to the marrow nail not being within the bone tube - proximally or distally - or to the fracture being less suitable for marrow nailing. In this case a plaster cast must be applied additionally.

22. Do not neglect to inspect carefully as to whether an infection of the stab incision wound is developing. If there are any indications of an infection the wound must be re-opened.

23. Do not hesitate to expose the fracture site and the insertion place of the nail widely if there is an infection of the fracture. Both wounds have to be kept open for a prolonged period of time.

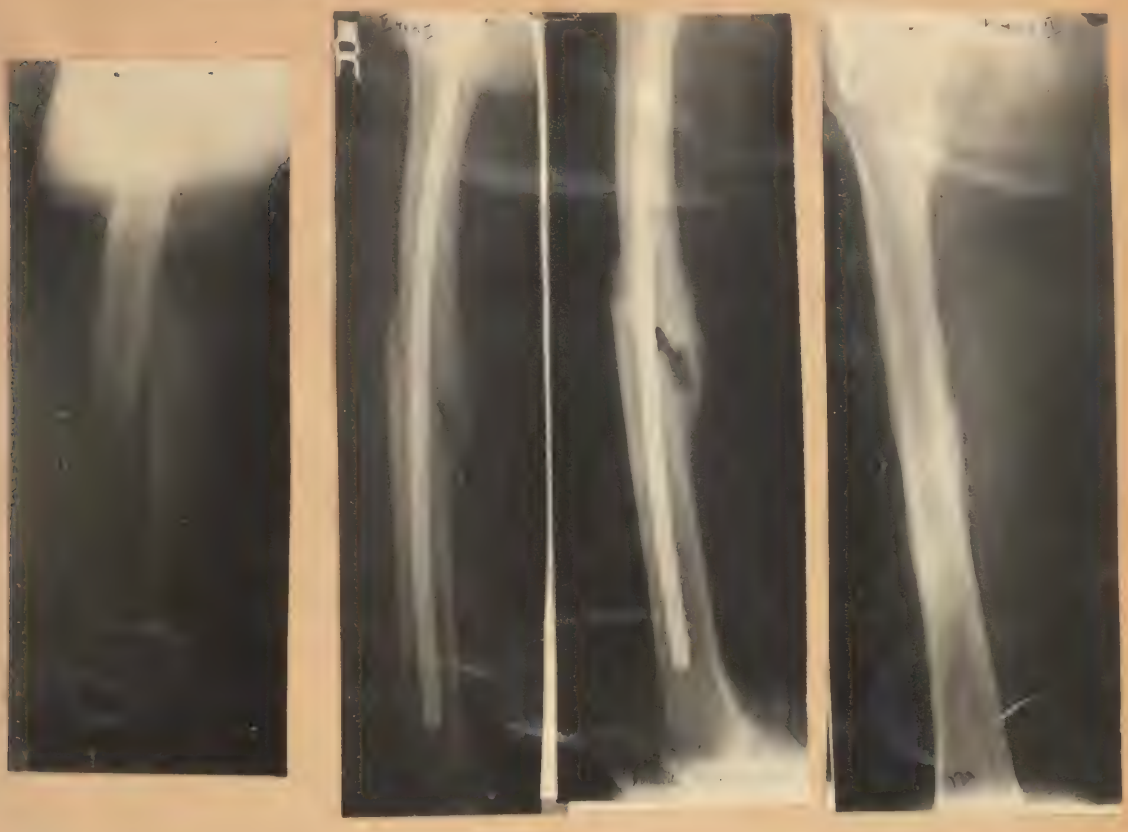
24. Do not pull the nail out because there is an infection. This is a serious mistake because it breaks the immobilization of the fragments.

25. Do not administer massage and passive exercises. They are superfluous and may even prove injurious.

26. Do not fail to re-examine the fracture regularly while under treatment and after the patient's dismissal. Otherwise wandering of the marrow nail and re-dislocation in less suitable fractures may be overlooked.

27. Do not remove the marrow nail too early. It must not be removed until fixation of the fracture is definite and no sooner than after 6 months time.

6. Some cases of percutaneous marrow nailing are shown below. X-rays of percutaneous marrow nailing.



a b c

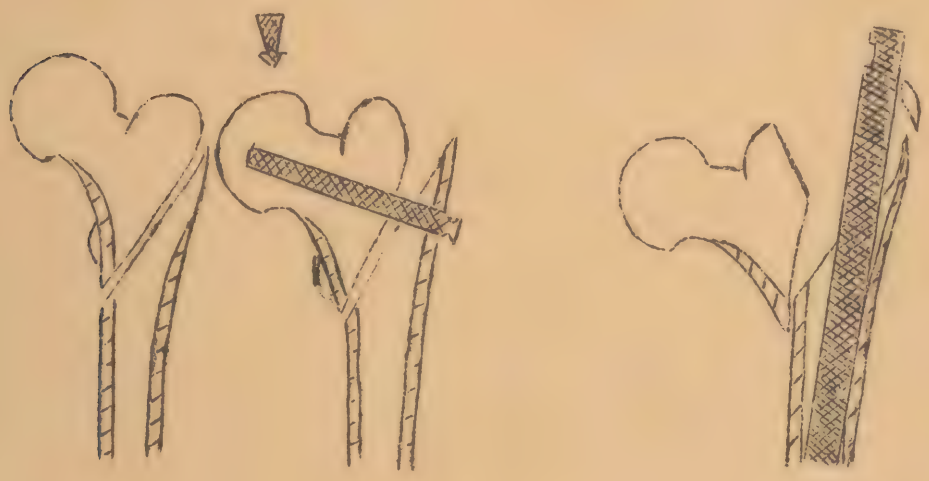
Illustration 87/I.
Fracture of the femur.
a) before marrow nailing
b) after the marrow nailing operation
c) after extraction of the marrow nail.

a b c

Illustration 87/II.
Spiral fracture of the femur.
a) before the operation
b) after the marrow nailing operation
c) after the extraction of the marrow nail.

b. Percutaneous marrow nailing of the pertrochanteric and subtrochanteric fracture.

In practically all cases pertrochanteric fractures show firm bony healing in the extension bandage. In spite of considerable abduction, coxa-vara position frequently results, which is due to the prevalence of the abductor muscles on the proximal fragment. Older people are the ones chiefly found to have this type of fracture. Application of the extension treatment will make them especially liable to pneumonia, failure of the circulatory system, decubitus, etc. For this reason some authors have made the attempt by using a nail for the neck of the femur, to getting the patients up earlier and have them move about. However, such fractures are less suitable for being nailed with a nail for the neck of the femur, although the nail has a firm hold all along the line of the neck, because on the distal fragment its fixation is very loose, being fastened there only in the hole of the lateral wall of the shaft and rotating in all directions (see illustration 88a).



a b

Illustration 88.

a) By nailing a pertrochanteric fracture with a nail for the neck of the femur no firm fixation can be obtained because the nail is fastened in the distal fragment only in the lateral wall of the shaft and will rotate there in all directions.
b) Using a marrow nail will also be a failure because the marrow nail will not be fixed firmly in the proximal fragment.

The attempts of fixing the pertrochanteric fracture cannot be successful with a marrow nail, as it has no firm hold in the soft spongiosa of the trochanter major.

Hence the author designed a combination of the nail for the neck of the femur with the marrow nail. Properly speaking this is no proper marrow nailing, because the nail in the proximal fragment is not fixed in the marrow

tube, but only in the spongiosa for its entire length. All the same, experience has proven that osteosynthesis thus obtained was extraordinarily stable. The nail for the neck of the femur is pierced through the marrow nail and it is fixed to it absolutely firmly and in addition the marrow nail fills the entire length of the femur neck. The first patient treated with it got up - unauthorized - the 3rd day after the operation without suffering any harm, and subjected the operated limb to weight bearing.

1. Shape of the nail.

The nail is approximately Y-shaped (see illustration 89).

The marrow nail piece is V-shaped, the component part that goes into the femoral neck is H-shaped in cross-section. The angle of the two pieces is fixed at 45°. The length of the marrow nail is 32 cm.; the femoral neck nail is available in the usual lengths. Practically all grades of inclination of the neck of the femur can be treated with this device, since the location of the nail here is not as important as in the nailing of medial fractures of the neck of the femur. Moreover the angle at which the broken neck of the femur stands to the shaft can be altered by increasing the abduction of the leg more or less. In 1940 the author had published reports on a large number of such nailings; originally he had always exposed the trochanter. No doubt this is dangerous in pertrochanteric fractures in so far as, depending on the location of the cleft of the fracture, the latter may easily be exposed too, which would increase the hazard of infection considerably. For that reason MAATZ made this nailing also through stab incision and by using a sighting mechanism. There are two incisions to be made, one for the marrow nail, the other for the nail of the neck of the femur. The procedure is as follows:

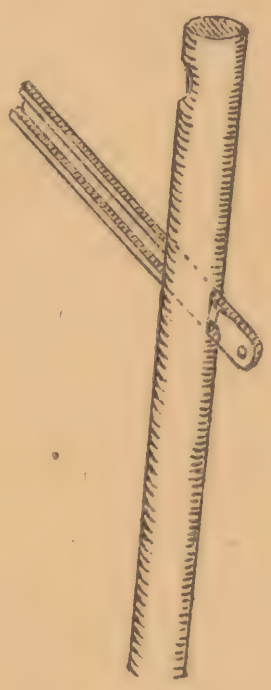


Illustration 89.
Y-nail for treating pertrochanteric and subtrochanteric fractures.

2. Position of the patient.

The patient is placed in the same way as in percutaneous marrow nailing of the femur neck, i.e. in lateral position. The injured leg is strongly abducted, i.e. elevated.

3. Introduction of the Y-nail.

The reduction usually does not cause any difficulties. The same manipulations as in nailing the neck of the femur have to be made. Ordinarily satisfactory results will be obtained by strong extension, abduction and inward rotation. Following the directions for marrow nailing of the femur, the marrow nail piece is first introduced into the marrow cavity. As the head of this piece is a tube, the guide rod is inserted into it before introduction and its point projects considerably beyond the nail. Now it is of the utmost importance that for introduction the marrow nail is turned into the proper position. Its perforation must concur with the direction of the axis of the neck of the femur. The slit of the nail must therefore be introduced in such a way that it points toward the femur head, in lateral position, f.i. it must be directed in a right angle downwards. If in nailing the neck of the femur one is accustomed to find the direction by means of a sighting mechanism one may do so here too. All devices built according to VALLS' principle are quite suitable. But it can also be done without any such sighting device. If there is a considerable medial rotation the slit of the marrow nail is exactly adjusted to the frontal plane of the body and then the nail is driven in. By a prominent part the nail is prevented from being driven in deeper than to a certain depth so that automatically the correct position of the marrow nail in the frontal plane is fixed, and, as mentioned above, only the correct direction of rotation of the marrow nail piece has to be determined. Then the guide rod is retracted and replaced by a guide bow which automatically indicates the spot where the second stab incision has to be made. (See illustration 90).

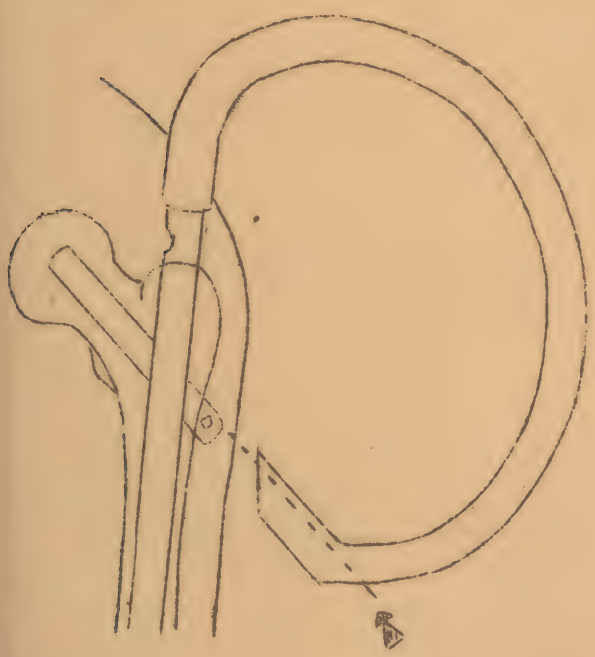


Illustration 90.
KUENTSCHER's guide bow for marrow nailing of pertrochanteric fractures. If fitted to the marrow nail the guide bow will indicate the place where the nail for the neck of the femur is to be inserted.

After the incision in the skin a strong Kirschner wire is drilled into the bone along the lower edge of the guide bow. It automatically passes the transversal perforation in the marrow nail. Not until now the first X-rays are taken in both planes as is commonly done in nailings of the neck of the femur. They will show whether or not the reduction is satisfactory and whether or not the marrow nail piece has been rotated into the proper position, i. e. whether the Kirschner wire runs in the direction of the axis of the neck of the femur. If one of the two requisites is missing, the Kirschner wire must be retracted, and either the reduction improved by an increase or decrease of the traction, the abduction or the adduction, or the direction of the rotation altered. To modify the position according to needs as seen from the

X-ray one may attempt to rotate the leg inwards or outwards extensively without altering the position of the marrow nail. Following the indication by the guide bow the Kirschner wire is once again drilled in carefully, and new X-rays are taken. If after all it is obvious that the aim cannot be achieved by rotation of the leg - as may be the case in jammed fractures - the marrow nail has to be withdrawn for 5 - 6 cm. Since its middle part tapers gradually, it is possible now to turn it around its axis into that position which the X-ray indicates as necessary. Then the nail is again driven in until arrested by the prominent part, and new X-rays are taken.

If it is now evident by these that the marrow nail is quite correctly in position, the Kirschner wire is removed and a hole is driven into the corticalis by means of a hollow chisel. The chisel is passed through the guide bow thereby. The piece of the nail for the neck of the femur is then introduced into this hole, and one can distinctly feel it when it glides through the slot pierced in the marrow nail. It is a serious fault to drive the nail through the slot by force. It becomes jammed very easily if it is not exactly in line. Only after it is felt absolutely distinctly that the nail has passed through the slot of the marrow nail, can the nail be driven forward with the hammer to the depth required. To determine the length of the nail for the neck of the femur it is not as important as in the ordinary nailing of femur necks, because the neck of the femur is preserved in its entire length here and some centimeters will not matter. In the end another set of 2 X-rays are taken. The skin wounds are closed by a few sutures. It is quite impossible that the part of the nail inserted in the neck of the femur can glide backwards, as is so often observed after ordinary nailings of the neck of the femur. It is firmly jammed with the marrow nail part and any forces trying to make it glide backwards will only wedge it still firmer, because they do not act parallel to its axis.

4. Further treatment.

It will not be necessary to place the p atient in a special position in bed. Associated injuries, such as muscle contusions, other fractures, etc. are very infrequent and it will be possible to get the patient up, commonly after 3 - 7 days. Re-displacement of the fragments, wandering of the nail, etc. has not been observed in a single case out of the 60 Y-shaped nailings so far performed. Early and marked callus formation was always observed as is characteristic in that kind of fractures. The nail was removed 6 - 9 months later.

5. Examples.

The 77 year old female patient W. M. had slipped in the street and suffered a left-side pertrochanteric fracture with marked comminution. Her general and nutritional condition were not particularly good, and therefore compli-

cations were very likely if she was confined to bed for a long period. For that reason marrow nailing was performed, although, because of a seriously splintered shaft, the fracture was not particularly suitable for the operation (see illustration 91).

a b

Illustration 91.
Pertrochanteric comminuted fracture of the 77 year old female patient W.M.
a) before the operation
b) 6 months after the operation.

The operation was performed under lumbar anesthesia, healing went on smoothly. Because of an extraordinarily splintered shaft the result of the reduction was not ideal. None the less the patient got up as early as the 5th day. A shortening of 1½ cm. resulted. No stiffening whatever of the joints was noticeable.

Usually, however, shortening or any other dislocation will not occur and the results are perfectly ideal. It may be demonstrated by the following examples of various kinds of pertrochanteric fractures.

a

b

c

d

Illustration 92.
Pertrochanteric fracture of the 67 year old female patient H. S.
a) before marrow nailing
b) after the marrow nailing
c) shortly before extraction of the nail
d) After removal of the marrow nail 6 months later.

a b

Illustration 93.
Pertrochanteric fracture of the 62 year old female patient H. H.
a) before marrow nailing
b) after the operation

a b

Illustration 94.
Pertrochanteric fracture of the 69 year old male patient R. S.
a) before marrow nailing
b) after the operation.

Illustration 95 demonstrates a marrow nail operation with the use of an extraordinarily thick marrow nail of 18 mm, pierced by an ordinary nail for the neck of the femur. This patient was a 77 year old female. Such a wide marrow cavity must be regarded as a very exceptional case. In practically all other instances the Y-nail as referred to will do.

a

b

Illustration 95.
Pertrochanteric fracture of the 77 year old female patient P. An extraordinarily wide marrow cavity made the use of an 18 mm marrow nail necessary.
a) before marrow nailing
b) after the operation.

c. Percutaneous marrow nailing of the leg.

On the leg only the tibia comes into consideration for marrow nailing as it only has the function of bearing weight. The fibula serves only as a place for the insertion of the muscles. Even in extensive defects of the fibula the leg is in no way hampered in its function. (See chapter VI). In addition the fibula is surrounded by strong fascial compartments of muscles and for that reason tends to heal excellently. It therefore heals much more quickly than the tibia and pseudarthroses are extremely rare. If they occur in exceptional cases and cause trouble by pains, resection should be given preference over any other operation.

1. Shape of the marrow cavity.

At its medial part the marrow cavity shows a waist-like narrowing. The most narrow place is on the border between the middle and lower thirds. According to BOEHLER's measurements the diameter is 8 - 12 mm in adults. The middle third is small, the upper and lower thirds are wide. The middle part contains only a few spongiosa trabeculae while in the upper and lower third such trabeculae are only present on the walls. There is more spongiosa on the front wall of the upper part of the shaft, where the marrow nail is inserted, than posteriorly and this gives the nail a firm fixation (see illustration 96).

a b

Illustration 96.
Marrow cavity of the tibia;
a) the marrow cavity filled with barium, according to EHRMANN. Nearer to the heads of the joints the spongiosa increases considerably in density.
b) Position of marrow nail.

2. Shape of the marrow nail for the tibia.

No straight, rigid nail can be used in marrow nailing the tibia as in the femur, otherwise it would pass through the knee or ankle joint. Similar conditions prevail with regard to the humerus, radius, metacarpal and metatarsal bones, phalanges, tarsal bones and clavicle. In the ulna a straight rigid nail can be used by introducing it from the olecranon. On the other bones the nail has to be introduced laterally into the marrow cavity. It is introduced into the marrow cavity through a lateral hole and only in its further course does the nail take the direction of the marrow cavity after having "turned a corner". Originally the author solved this somewhat difficult technical problem by using a marrow nail consisting of several longitudinal lamellae. At the point of the nail these lamellae were firmly joined, whereas at the head they were held together by a screw. When the screw was loose, the nail was flexible and able to "turn a corner" easily.

After reaching the desired position in the bone the screw was tightened and thus the nail became a rigid form. E. POHL improved this flexible-rigid marrow nail considerably by manufacturing it from a spiral wire. In the center of this spiral wire there is a strong core which can stand the traction of several hundreds of kilograms. By stretching that core, which is done by tightening a screw at the head of the nail, this marrow nail will become extraordinarily rigid.

Such nails are complicated and hence costly. Furthermore they are more readily liable to corrosion owing to their extensive contact surfaces subjected to friction (see chapter III and IV). In marrow nailing of markedly curved femurs the author had the experience that straight nails were bent to conform by the successive blows, and nailing did not meet with any difficulties. All marrow nails used presently for the tibia, humerus, etc. are manufactured according to this principle. By choosing a somewhat thinner sheet metal and employing a U-like profile, E. POHL has succeeded in making the nail in one plane still more flexible so that the "corner" can be "turned" now very easily. Of course the flexibility thus obtained reduces the stability of the osteosynthesis essentially against flexing in the "corner plane". This drawback may be removed or at least lessened by driving another flexible marrow nail in close to the first one. It will quite as readily turn the corner. Both together will give sufficient rigidity to the extremity (see illustration 97).

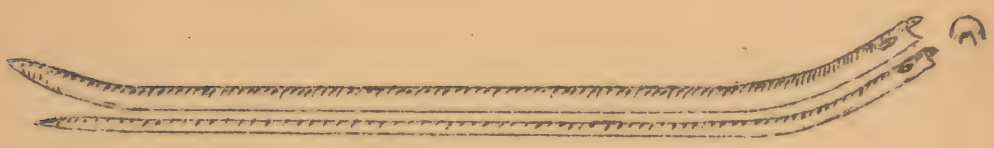


Illustration 97.
Marrow nail for the leg.

The nails are U-shaped in cross-section. In diameter they are 8 and 9 mm. They are supplied in lengths of 24 - 39 cm., graduated at the rate of 1½ cm.

3. Position of the patient.

The leg is placed with the knee slightly flexed. This will be possible on any ordinary extension table by using a knee support. Still more advantageous is the well-known BOEHLER extension apparatus for the leg. Instead of piercing the heel-bone with an extension wire a canvas strap is buckled to the foot and traction exercised, placing a spring balance in between. Shortening can easily be removed by

tightening the screw of the extension apparatus. The area of the tuberositas tibiae is draped with a sheet with a hole cut in it. In using the BOEHLER apparatus the upright rods of the knee support on both sides of the knee are a little awkward (see illustration 98).

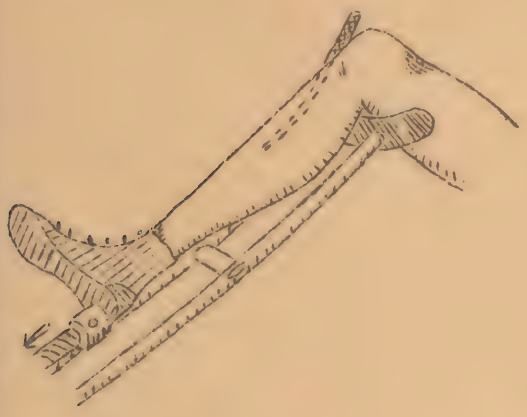


Illustration 98.
Placement of the leg in marrow nailing.

Marrow nailing will also be possible if the leg is flexed at an angle of 90° hanging from the edge of the table. The assistant can make the reduction by a strap buckled to the foot of the patient.

4. Introduction of the marrow nail into the leg.

A longitudinal incision of about 2 cm. is made approximately 1½ cm. above the upper border of the tuberositas tibiae. Just above the tuberositas there usually is a deeply marked groove in the bone behind which the extensor tendon is attached. The joint capsule is at least 2 cm. above that place. The joint therefore is by no means threatened with exposure. The operator takes a sturdy square awl and pushes it through the groove into the tuberositas anterior to the attachment of the tendon in the direction of the marrow cavity. The puncture should be made as flat as possible. Therefore the handle of the awl is lowered until it touches the patella. The awl should be thick and sturdy and not thin and tapering sharply into a point. Piercing the bone and the marrow cavity is done easily and without trouble by pressing and twisting the awl to and fro, the bone substance at this place being soft and porous. The awl is pushed ahead until it strikes the posterior wall of the tibia, which cannot be penetrated as easily as it is very hard at this place. In boring the hole the essential point is - and this should be emphasized once more - that it should be made at as flat an angle to the axis of the tibia as possible. It is demonstrated in illustration 99.

From the various lateral X-ray views within this book the groove above the tibia and the line of direction of the hole bored may be seen. It can be recognized therefrom that the tuberositas tibiae varies considerably in size and protrudes with differing extent. Yet always it will be possible to get into the marrow cavity conveniently from the designated spot. The entrance of the awl into the marrow cavity will be indicated by a little marrow fat

Illustration 99.
Drilling a hole for the marrow nailing of the tibia by using an awl.

oozing out of the bored hole beside the awl when it is driven in. The nail is introduced without using a guide rod. A springy marrow nail of appropriate size and length is introduced into the hole and driven in with hammer blows of moderate force. The left hand of the operator presses that part of the nail which projects out of the hole downward towards the patella to assist the nail in taking its course as flat as possible. It will be advisable to protect the nail from contacting the skin. BOEHLER uses a very suitable curved metal plate which protects the skin from injury (see illustration 100).

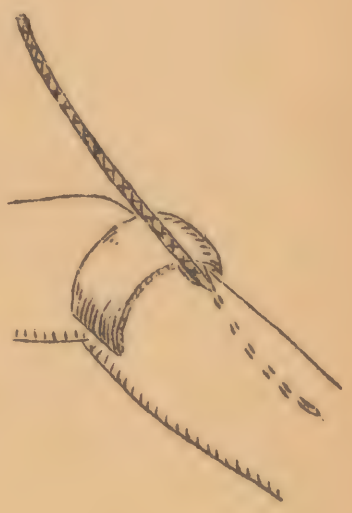


Illustration 100.
BOEHLER metal plate to protect the skin from contusion by the marrow nail.

The nail is slightly curved. It is introduced with the concave part toward the rear, toward the marrow cavity. It is springy only in an anteroposterior direction. Its point is blunt and especially shaped so that on striking upon the bony rear wall of the marrow cavity it will turn forward and thus the nail will glide downwards when it is driven in further. This striking of the point against the back wall can be distinctly felt and the gliding down of the nail likewise. Should it be stopped right after insertion, this is due to the back wall being struck at too sharp an angle and thus the nail cannot advance further. With some practice this is felt immediately. It can also be ascertained very well by a brief fluoroscopic checkup. Nailing of the leg can only lead to a failure if the nail is driven in too steeply, presuming that the thickness of the nail is correct. It can be readily remedied by driving the nail in at a more acute angle and by correcting the bore hole appropriately with the awl. Pressing the head of the nail down is greatly facilitated by using a driving-in implement for the leg (see illustration 101).

The marrow nail can be shaped so it will glide along the back wall of the marrow cavity by curving the nail point slightly anteriorly. It is best done by putting the point into the slot of the hammer used for removing the nails and then lifting the handle of the hammer (see illustration 102). However, the point must not be bent so much as to render it difficult or even impossible for the marrow nail to enter the distal fragment. It will frequently be necessary also in marrow nailing the humerus or forearm to give the nail a special curving in this way (see illustration 102).

Driving the nail in farther will then proceed very quickly. With leaded rubber gloves on his hands the assistant checks the advancing nail by short exposures with the fluoroscope. Looking over the shoulders of the assistant, the

Illustration 101.
Implement for driving in the marrow nail of the leg. The head of the nail is pressed downwards while the nail is driven in.

operator can observe the screen too. In most cases of fresh leg fractures lateral dislocation will disappear simultaneously with the application of traction. Otherwise it can be easily removed by manipulation through the assistant when the nail is introduced into the distal fragment.

Then the nail is driven into the distal fragment as deeply as possible. The upper end should be left extending out beyond the tuberositas by about 1 - 1½ cm. and must not be driven in too far, otherwise its removal later on may be difficult. The incision wound is closed by 1 - 2 button sutures. Should the nail fail to catch the distal fragment one will observe it in the fluoroscope. Then the nail is withdrawn a little with the hook which fits into the eye at the nail's head. One can also drive the nail a little back by means of a ram inserted into the eye.

In fractures of the shaft of the femur the length

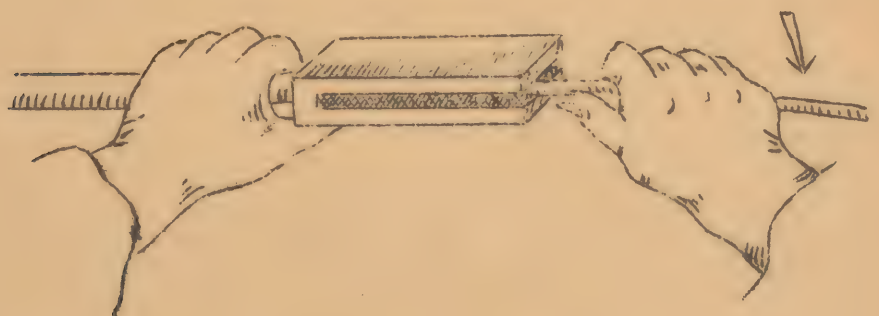


Illustration 102.
Bending the marrow nail in the slot of the hammer used for removing the nail.

of the nail will not matter so much. From the tip of the trochanter it may protrude even 4 cm. and it will not matter

much. Commonly the nail should be chosen as long as possible as thus the fragments are engaged more firmly and from experience we know that long nails do not cause any trouble whatever. Yet in fractures of the tibia the length of the nail is very important. Upwards it must not extent too far beyond the tuberositas, otherwise it may pinch under the skin. Downwards there are also limits in as much as the nail must not approach the foot joint too closely. In those cases where on the X-ray the nail's point was about 1 cm. away from the joint cleft no trouble was observed. No nail was driven in beyond that point.

The size of the nail depends on the size of the marrow cavity. The nails are supplied 5, 7 and 9 mm in diameter. Since much depends on the length of the nails as already mentioned above, they are made in 12 lengths, varying from 180 to 390 mm.

In most cases the sizes of the marrow cavity will allow introducing 2 nails successively. For that purpose the nails must have been adapted to one another previously. As described the thin nail is driven in first. Care must be taken that it is not dragged along with the second nail and thus introduced deeper and ultimately disappears entirely in the marrow cavity. Therefore it must be held back by a piece of wire fixed to its eye or by a pronged curved bone hook when the second nail is driven in. Only the use of 2 nails will enable the patients to get up a few days after the nailing. If only one nail is used the patients cannot get up earlier than 3 weeks after nailing. None the less the results will be excellent even in these cases. A few days after nailing exercises can be made in the bed (knee bending, foot moving, pressing the leg against a support).

In contradistinction to the femur the marrow cavity of the tibia is not equally wide, medially it is waist-like. Towards the ankle it is often very wide. Therefore fractures of the lower third of the tibia cannot be nailed satisfactorily with the nails described. Lateral slipping off would certainly be prevented but not slight angulation, a circumstance which deserves the closest attention. This disadvantage can be avoided by using spread nails. The initial spread nails invented by the author consisted of two nails between the points of which an olive-shaped metal wedge could be moved. By tightening a screw at the head of the nail the wedge was moved upwards towards the head by means of a wire, thus forcing the points to diverge. R. MAATZ has improved this nail by fixing the wedge firmly to the outside nail. This nail is driven in first. The thinner nail will then be separated from the former when passing the wedge. It must be considered a disadvantage of these nails that a large assortment of them has to be kept available because they must not only be at hand in varying lengths but in addition the wedge has to be fixed at different distances from the point (see illustration 103).

These nails have been of good use in practice. "Stable osteosyntheses" will be possible even in fractures

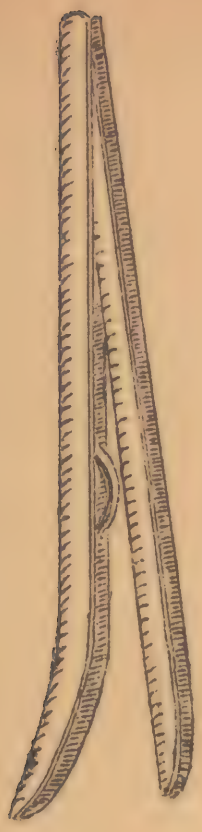


Illustration 103.
Spread nail for the leg according to R. MAATZ, with a wedge fixed firmly to the outside nail.

of the lower third. When removing the nail it must be strictly observed that first the inner, thinner nail is removed, otherwise removal will be rendered impossible. In addition R. MAATZ has reported about a rotating spread nail where, by an axis rotation of the inner nail, the nail is made to spread. According to reports from H. GRIESSMANN, and W. SCHUETTEMEYER they were not quite as satisfactory as the other nails.

5. Further course.

In most cases no special position of the patient is necessary. If there is a large swelling it will be advisable to give the leg an elevated position on a cushion or Braun splint for 8 - 10 days. This may also be of advantage in many cases of "unstable osteosynthesis" as a supplementary fixation, otherwise a plaster or traction cast may be applied. Ordinarily getting up and putting weight on the limb will be possible a few days earlier than in femoral marrow nailings, and accordingly dismissal from the hospital. Yet in leg fractures, much more stress has to be laid upon regular re-examinations, because in less suitable fractures the initially "stable osteosynthesis" may disunite again after some weeks as the marrow nail

is held partly only by the spongiosa. Usually the patient himself has the feeling as if the limb was loose when walking. It will suffice usually to apply a walking cast for some weeks as a supplementary measure and only in exceptional cases will confinement to bed be necessary.

The nail should be removed no earlier than after 6 months.

The way the marrow nail is introduced laterally into the bone tube in human beings, due to the anatomical form of these tubes (in dogs the leg can be nailed with a rigid straight nail - chapter VI -) and the slightly curved line of the marrow nail which is enforced thereby are responsible for the fracture showing a slight recurvation after nailing. This recurvation is usually not particularly marked and therefore tolerable as a trifling dislocation ad axin, more so as from nature the leg is slightly curved anteriorly. Should, however, this dislocation be marked it must be corrected. This matter demands most careful consideration. After the skin wound has been sutured, to best advantage the operator himself undertakes the correction. As prescribed by MAATZ the leg is placed on a triangular wooden bolster or pelvis support with the fracture site on top of the bolster. By pressing it down with both hands, using thereby his own body weight, the operator will succeed in bending the double nail straight and thus remove the recurvation (see illustration 104).

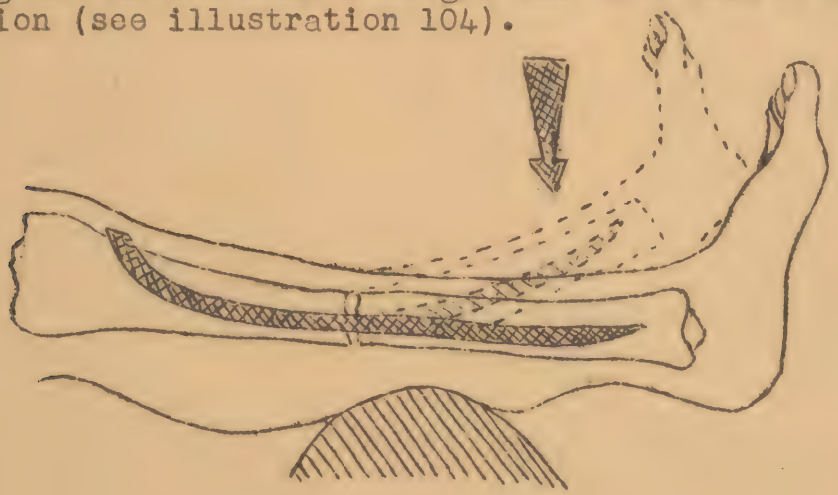


Illustration 104.
Removal of recurvation after marrow nailing of the leg by bending the leg over a triangular wooden bolster.

If the upper or lower foot joint is stiff, leg fractures, according to the author, can be nailed from the distal approach with a straight rigid nail (see chapter VIII).

6. Faults and risks in performing marrow nailing of the tibia.

Most of the faults and risks stated on page 201 - 203 in reference to femoral marrow nailing apply as well in this case.

There is still another danger in marrow nailing of the leg in as much as the nail may have been introduced too proximally and the knee-joint has been exposed thereby. It

can be prevented with certainty by starting to drill the bone exactly at the place indicated; besides any such case has not been reported so far. No doubt the most imminent danger lies in the perforation of the rear wall of the bone tube while the nail is driven in. This can be averted also with certainty by starting to bore the hole sufficiently flatly, by curving the point of the nail and by directing the head of the nail correctly while driving it in. If a double nail is used strict care has to be taken that the heads of both nails are on the same level while they are driven forward.

7. Some descriptions of marrow nailing of the leg.

Some examples showing marrow nailing of the leg are illustrated herewith. Illustration 105 shows:

a b c

Illustration 105/I.
Fracture of the tibia in the lower third:
a) before marrow nailing
b) after marrow nailing
c) after extraction of the marrow nail.

a

b

c

d

Illustration 105/II.
Fracture of the tibia in its upper third.
a) before marrow nailing
b) after the operation
c) after several weeks
d) after extraction of the marrow nail.

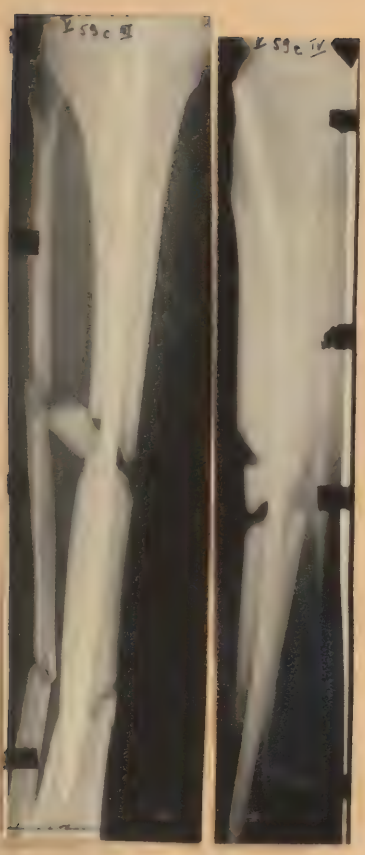
a

b

c

Illustration 105/III.
Fracture of the tibia in its median part.
a) before marrow nailing
b) after the nailing operation
c) after extraction of the marrow nail.

a



b

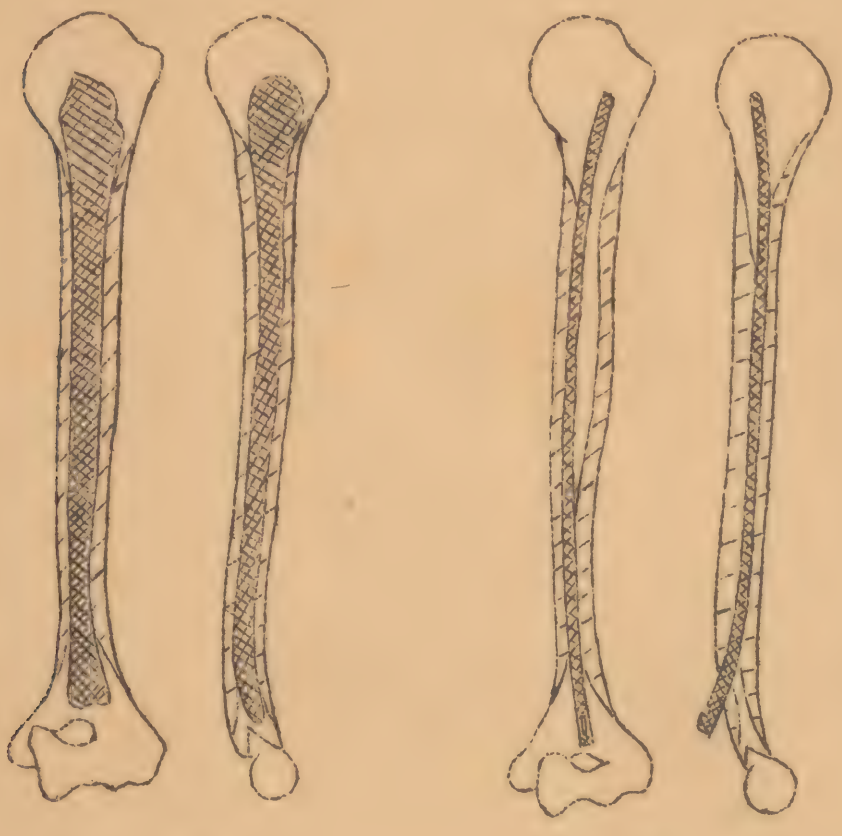
c

Illustration 105/IV.
Multiple fracture of the lower leg.
a) before marrow nailing
b) shortly after the operation
c) shortly before extraction of the marrow nail.

d. Percutaneous marrow nailing of the humerus.

1. Shape of the marrow cavity.

It is wide at the head of the humerus and gradually narrows towards the elbow joint. The smallest passage is in the distal third where it is 6 - 9 mm in width. Here also are solid spongiosa trabeculae. A view of the marrow cavity is shown in illustration 106.



a b

Illustration 106.
a) Marrow cavity of the humerus filled with barium pulp according to EHRMANN.
b) Position of the marrow nail.

2. Shape of the marrow nail for the humerus.

The form of the nail used is the same as used in children's leg fractures. For wide marrow cavities the short marrow nail as used for adults in femoral fractures may be appropriate. In elbows where the joint is stiff a straight rigid marrow nail may be used by nailing the humerus from the olecranon.

3. Position of the patient in percutaneous marrow nailing of the humerus.

The patient is placed on the table in the dorsal position. Yet he must not lie as is commonly the rule in the

middle part of the table, but with the shoulder of the injured side extended considerably beyond the edge of the table. Traction is applied to a hand cuff and counter-traction to the armpit of the same side by means of a sheet or broad padded strap running diagonally across the chest and back. The arm is abducted about 45 - 60 degrees (see illustration 107). HAEBLER applies wire

Illustration 107.
Position of the patient for marrow nailing of the humerus.

extension through the olecranon and works with the lower arm flexed.

The X-ray unit is placed on the floor and is movable there. Its beam is directed upwards. The roentgen screen is put on the arm and rotated around its longer axis while fluoroscoping. The nail should be selected with special care. When the nail is inserted from the distal end it should, if possible, extend as far as the neck of the humerus and in proximal nailing to the end of the marrow cavity. The bone certainly varies considerably in width and in most cases there will be room for 2 nails. Yet, sometimes it may happen that the marrow cavity is so small that it can take only the thinner nail. In marrow cavities diminishing rapidly in width it will be possible to use the thicker nail much shorter in size if the nailing is done from the tuberculum; thus the thinner nail will go through the whole marrow cavity even to the end but the thicker one less far.

On cross-section the marrow cavity of the humerus is not round but oval shaped, i.e. sagittally its width is greater than anterior-posteriorly. This must be taken into consideration when choosing the marrow nail, the size of which is determined by the frontal X-ray view.

4. Introducing the marrow nail into the humerus.

As in marrow nailing of the leg the nail is introduced into the bone tube through a lateral hole. The hole can be made proximally or distally. Proximal fractures are nailed from the distal fragment, and distal fractures from the proximal end, following the principle strictly prescribed to introduce the nail as far away from the fracture site as possible. In fractures of the median part of the shaft, of course, this rule is of minor importance. In these cases proximal introduction of the nail is of best advantage, as it facilitates the operation. Initially the author used to nail the humerus distally. The nail was introduced through a hole bored on the extensor side of the humerus, 1 - 2 cm. above the fossa olecrani which excludes the risk of exposing the elbow joint. The bore hole is in conformance with the diameter of the nail and runs in very obliquely in the proximal direction towards the marrow cavity; to best advantage it is made with an electric drill. A skin incision of about 2 cm. is made longitudinally to the arm. The triceps tendon is not pierced but held away towards the radial side. The bore hole must be exactly in the axial line of the bone tube. The nail has to be chosen as long as possible. It must extend approximately 6 cm. deep into both fragments. The thickness of the nail must be in conformity with the width of the marrow cavity. The hole may be widened with an awl whereby the latter should be held as obliquely as possible, that means in the direction of the marrow cavity. Care should be taken to avoid splintering of the bone.

Regarding marrow nailing of the humerus from the proximal part there is a report from C. HAEBLER. The arm is abducted 30 degrees, overextended posteriorly and rotated inward with the forearm flexed to 90 degrees, so that the hand comes to lie at the crest of the ilium. In that position the tuberculum majus can best be felt and is readily accessible.

The place the nail is inserted is below the tuberculum majus, closely behind the crista tuberculi majus. The place below the tuberculum, respectively its lower border, has to be chosen because otherwise trouble might arise with the bursa subdeltoidea, the subacromial side-joint and besides the nail might strike the acromion if abducted.

Due to the inward rotation of the arm as mentioned above, the incision site is located anteriorly somewhat laterally and runs from the tuberculum majus 3 - 4 cm. downward. After the incision in the skin and in the fascia has been made, the fibers of the deltoideus are pierced bluntly. If a branch of the arteria circumflexa humeri appears at the upper angle of the wound it is doubly ligated and severed, and the bursa, if it appears at all, is displaced upwards.

The awl is applied as flatly as possible, below the tuberculum majus close behind the crista, and the marrow cavity is opened with a few hammer blows, one edge of the awl in the anterior position. As soon as the awl has been

pushed 1 - 2 cm. deep into the bone the hole is widened with the Lexer chisel or a drill cutter to a triangle with the point directed distally, until there is sufficient room for the nail. The awl must be directed as flatly as possible lest the opposite wall which is very thin there, is pierced. Then the arm is adducted as much as possible and the marrow nail introduced into the hole. Advantageously the point of the nail is curved a little with the slot-hammer to increase still more the curved form of the nail and thus making it glide more readily off the opposite wall of the bone tube. Directly after the point has been introduced into the hole the head of the nail must be pressed toward the shoulder, thus assisting the gliding down without hurting the opposite wall. If strong resistance is felt immediately after having started with the driving in, it is an indication that the nail is directed too steeply upon the opposite wall and therefore is hindered from gliding downwards. Then the line of the hole must be made flatter, the point of the nail more curved and the head of the nail pressed more medially. Then the marrow nail is driven in further until just before the fracture site. Reduction is performed by extension and lateral adjustment. Usually the reduction can be obtained readily and a guide rod is not absolutely necessary. As in marrow nailing of the leg one can do without it, because in both cases the nail can easily be driven forward and pulled back. If needed, a strong Kirschner wire can be used as a guide rod but its end must be filed to a round shape beforehand. If it remains pointed it gets entangled in the little rough places in the wall of the marrow cavity too easily. In this case too the nail is of good use as an auxiliary implement in the reduction. If the reduction cannot be obtained in the position described above, one must elevate the arm anteriorly and then the reduction will always be a success. Since the nail is slightly curved the point of the nail tends to turn exteriorly. Therefore to best advantage the distal fragment is given a slight angulation externally. After the nail has penetrated 2 - 3 cm. into the distal fragment, attention must be directed once again upon correct reduction which now can be improved very easily. Thereupon the second, inside marrow nail is driven ahead until it is on an even level with the head of the first nail, both nails are now driven home together. The distal part of the marrow cavity consists of fairly solid bone tissue which cannot as readily be pierced by the nail. There will also be no danger of harm being done to the surface of the joint as it is located at a distance of 3 - 5 cm. and the nail if it leaves the marrow cavity distally, diverges considerably posteriorly. Yet, danger will be imminent if the nail has been chosen too long. Then the fragment surfaces will be driven away from each other. At any rate the fragments must be vigorously pressed together when the nail is driven in. Finally they must be forcefully impacted by blows upon the flexed elbow. The head of the nail must extend $1\frac{1}{2}$ - 2 cm. beyond the bone. The wound is closed in the usual way. Similarly as in nailings of the leg it may perhaps be necessary to eliminate angulation of the arm, caused by the curved nail, by bending it straight upon a wooden triangular bolster.

5. Further procedure.

Application of an abduction splint or a fixation bandage is superfluous if the osteosynthesis is stable. The wound should be covered with a sterile dressing, and further dressing is not necessary. An arm sling is permitted only for the first 4 - 5 days. Then the patient should exercise the arm voluntarily. Attention must be directed in the first place to any abduction. If there is still motion in the fracture an additonal plaster cast has to be applied. HAEBLER recommends a U-splint. Starting from the armpit it embraces the elbow flexed to 90 degrees and extends externally to the head of the humerus. Thus the shoulder-joint can be conveniently moved. This splint is left on for 3 - 4 weeks. The patients can be dismissed from the hospital after 8 - 10 days on an average and may take up their duties after 3 - 4 weeks. If, in heavy workers, a thin nail has been used, caution must be observed. Such thin nails may break in heavy work. Re-examination must be made at regular intervals of 4 - 6 weeks.

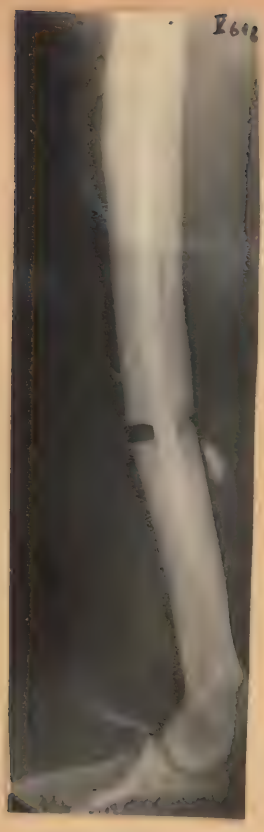
The marrow nail should not be removed before 12 weeks have elapsed.

6. Faults and risks in marrow nailing the humerus.

On the whole the same remarks apply as made in regard to the femur, although there is not so much the danger of shock due to continued hammering and attempts of reduction and less risk of chilling because the patient lies on an ordinary table and is not for the most part of his body exposed so much as on the extension table. If marrow nailing is done from the distal fragment the point of the nail may be entangled in those solid spongiosa trabeculae which are present there. If the marrow nail meets with resistance just after it has been introduced it must be withdrawn at once and the hole made flatter at the upper side and widened by means of a twist-drill or an awl. If the marrow nail has been introduced distally and it is too long it will be a threat to the shoulder-joint, especially if the fragments were driven away from each other in advancing the nail and have to be impacted again. This may happen easier in the upper extremity due to the considerably weaker muscles there. When the marrow nail is driven forward in the distal fragment heavy strokes from the proximal part must be met by strong counter-pressure. In nailing from the proximal fragment it may easily occur that the opposite wall is perforated. Furthermore it may happen that the marrow nail failed to get into the bore hole and is driven along the outer wall of the bone tube and along the periosteum where the resistance offered resembles that met in the bone tube. Any mistake will be discovered easily by the fluoroscope.

7. Examples demonstrating marrow nailing of the humerus.

Some examples may be demonstrated herewith to elucidate matters further:

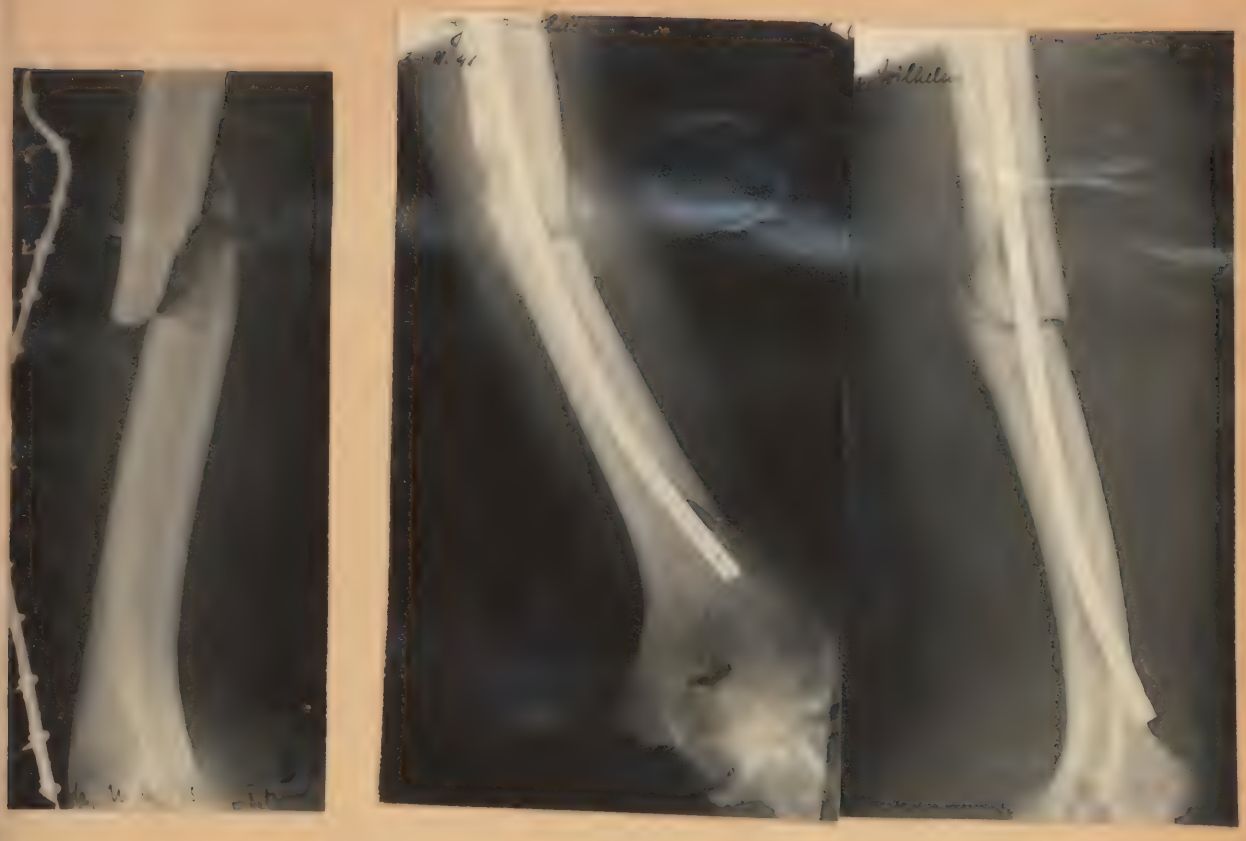


a

b

c

Illustration 108/I.
Fracture of the humerus.
a) shortly after the marrow nail operation
b) shortly before the extraction of the nail
c) after extraction of the nail.



a b

c

Illustration 108/II.
Fracture of the humerus in its median part.
a) before marrow nailing
b) after marrow nailing
c) after extraction of the marrow nail.

e. Percutaneous marrow nailing of the neck of the humerus.

The nailing of the neck of the humerus appears to be analogous to the nailing of the neck of the femur. VOSS indeed suggested introducing a short nail from the outside shaft into the head analogous to the Smith-Petersen nail in fractures of the neck of the femur. Yet there are quite different conditions prevailing at the shoulder. There is practically no "neck"; there is only the transition from the head into the shaft. Therefore the nail has no firm footing distally and it needs always some additional fixation. Due to these anatomical circumstances the exposure of the fracture cleft and hence also the joint can hardly be avoided if a short nail is used. Thus 2 advantages which are present in the nailing of the neck of the femur cannot be utilized for the nailing of the neck of the humerus. Consequently the aim must be to counterbalance the handicap. It can in fact be accomplished by using a long marrow nail. Then it is certainly no longer true marrow nailing because one part of the nail does not rest in a marrow cavity but rather only in the spongiosa of the head of the humerus. Owing to its length the nail is very firmly fixed distally and the insertion place is at a sufficient distance from the fracture cleft, much more distant than it is in nailings of the neck of the femur.

Thus the operation indeed is analogous to the extra articular nailing of the neck of the femur according to SVEN JOHANNSON and JERUSALEM and similar to that it is a typical operation in all its details. It was described by the author in 1940.

The indication is given when the X-rays show the fracture in a bad position, i.e. if it is known from experience that a reduction is necessary which according to experience cannot be held firmly in position in a plaster cast, or if an originally well engaged fracture, maybe even an impacted one, has slipped off in the course of the splint treatment. There will be no mechanical biological indication as in the neck of the femur, because such high tension maxima are not present here. It is a condition for the operation that the head of the humerus is intact and not comminuted which condition would not give the point of the nail a footing.

The operation should be made as early as possible as thus the reduction is also facilitated. The operation of fresh fractures is easily possible within the first 48 hours under local anesthesia. An anesthetic solution is injected in the region of the fracture hematoma, and the insertion site and its vicinity are made anesthetic by infiltrated anesthesia. The author prefers, however, evipan-ether narcosis.

The patient is placed in the dorsal position. Thus the body weight counteracts the traction of the reduction. Besides it will be advisable to sling a broad strap around chest and table by which the body is firmly fixed. This position is similar to that used in nailing the humerus. (See Illustration 107). The arm is elevated about 90 de-

grees and abducted 45 degrees. This anterior position is most important because the reduction will often be possible only in that position. The X-rays are taken in two planes. In the anterior exposure the plate-holder is placed under the shoulder and the tube in front of the shoulder. In lateral exposure the plate-holder is put on the curvature of the shoulder up to the neck, the beam is directed towards the axilla. In switching over from one line of exposure to the other the tube need be given only a slight swing, and using 2 tubes will therefore be not as advantageous as in the nailing of the neck of the femur. Strong traction on the arm can be applied by a screw extension device fixed to the operating table. To best advantage the elbow joint is placed in a flexed position. The operative field is at the same small place as in marrow nailing of closed fractures of the humerus from the distal fragment, i.e. at the exterior side of the humerus just above the elbow joint. By applying strong traction and rotation to and fro any interlocking is loosened. Then as usual the marrow cavity is distally obliquely opened with an electric drill and the nail is driven in. The correct length of the nail is of the utmost importance. If it is too long and in an unfavorable position it may perforate the joint surface. If it is too short it is not inserted deeply enough in the head. One should also consider that the fracture will close a little once the extension has been slackened. X-rays often give a false impression as to the length of the nail. They may show the nail more extended in length due to the described technique in taking pictures. Therefore it is most essential to choose the length of the nail with particular care by the X-rays on hand before the operation, and various sizes should be kept available. If the hole is made 2 - 4 cm. farther proximally, it will not matter except risking harm to the radial nerve. By proceeding cautiously this can be safely avoided. If the marrow cavity is very narrow one nail only is used. However, ordinarily the marrow cavity is wide enough to allow the use of a double nail which will be fixed at two places in the head. Spread nails may also be used with good advantage. (See illustration 109).

First the thinner nail is driven in up to the fracture site or even 1 cm. deep into the head. This can be checked by the assistant with the fluoroscope. Experience of the author has shown however, that X-ray pictures cannot be dispensed with to control thoroughly the position of the fracture and nail because the contours of the shoulder skeleton cannot be recognized sufficiently distinctly on the fluoroscopic screen. Therefore pictures should be taken by using a rapid developer in the same way as done in nailings of the neck of the femur. The result of the reduction will then have to be corrected according to the pictures, if necessary. Ordinarily the shaft of the humerus must be moved somewhat externally by placing the fist in the axilla or by strap traction. It must be considered thereby that in contradistinction to the conditions prevailing in the nailing of the neck of the femur, the nail does not change the line towards the distal fragment. Its position is always correctly in the marrow cavity. Since its point tends to glide laterally along the wall of the

Illustration 109.

Fracture of the neck of the humerus, the marrow nail has been introduced distally.
a) before the nailing
b) after the nailing

marrow cavity it is recommended to curve the point a little medially before it is introduced. No guide rod will be necessary. If the reduction is satisfactory the position of the nail is also correct and the direction the nail moves through the head can only be altered by altering the position of the shaft of the humerus. By elevating the nail to a noticeable degree it will move downward through the

head and vice versa by lowering the arm it will move more upward. On the other hand by moving the arm anteriorly the point of the nail will advance posteriorly, and in abducting the arm more anteriorly. All this can be recognized from the X-ray pictures taken during the operation. First, one of the 2 marrow nails is introduced and advanced in the direction desired and then the other. Afterwards the fragments are impacted as in nailing the neck of the femur. The elbow joint is flexed to that end and heavy blows have to be directed with the fist upon the proximal humerus fragment, headwards. These blows are repeated several times. The insertion site of the nail is closed by 1 or 2 sutures.

Special after-treatment will not be necessary. There is no special splint bandage necessary. Exercising the limb should be started early whereby particular attention should be directed to abduction. The position of the nail has to be checked 2 weeks later by the X-ray.

Faults and risks in performing percutaneous marrow nailing of the neck of the humerus.

The nails may have perforated the head and entered the joint. The nails have been driven in too deeply and either have to be retracted or replaced by shorter ones. The position of the fracture is bad. The nails have to be retracted and introduced anew after improvement in the reduction has been obtained.

f. Percutaneous marrow nailing of the forearm.

1. Position of the patient.

The patient is placed on the operation table in the dorsal position. The arm is adducted and the elbow flexed to 90 degrees. Traction is applied to the hand. The fingers are painted with mastisol and the hand embraces a wooden handle likewise painted with mastisol. Then the hand is firmly bandaged to the wooden handle with a solid sterile dressing which leaves the wrist open. Countertraction is applied to the forearm by means of a strap placed firmly around it near the elbow (see illustration 110).

Illustration 110.
Position of the patient in marrow nailing of the forearm.

It will be of advantage to apply some counter-traction also to the leg of the well side, as suggested by A. W. FISCHER and MAATZ. This will prevent the upper arm from being elevated over the strap due to the pull at the hand by which the elbow is stretched. This arrangement is in accordance with the position indicated by BOEHLER for the reduction of fractures of the forearm. For the application of traction on the wrist HALBLER suggests a leather strap as used by transport workers. 2 leather belts are sewed on this leather strap at a right angle and these belts have two slings which are hung in the traction screws of the extension device. Proximal to the bandage the skin is painted for a width of 1 cm. with mastisol and a sterile bandage dressed around wrist and leather bandage.

BOEHLER uses his well-known screw traction device. Traction is applied here by means of a leather strap running over the joints at the base of the 2nd to 4th fingers. Thus sufficient room is available to perform the nailing distally. The apparatus will also readily allow application of lateral traction. A. W. FISCHER and MAATZ suggest using a so-called "devil's fingers" on all 5 fingers. These also will readily allow distal marrow nailing.

Proximal marrow nailing can also be done as follows: The assistant takes the hand and draws powerfully because the traction power required for the reduction is not strong enough. Yet thus the assistant is unnecessarily exposed to the X-rays. In marrow nailing of distal fractures one X-ray unit will do. The tube is placed below the forearm.

By pronating and supinating the hand gradually a good stereoscopic view will be obtained as well as screen views in two planes at a right angle.

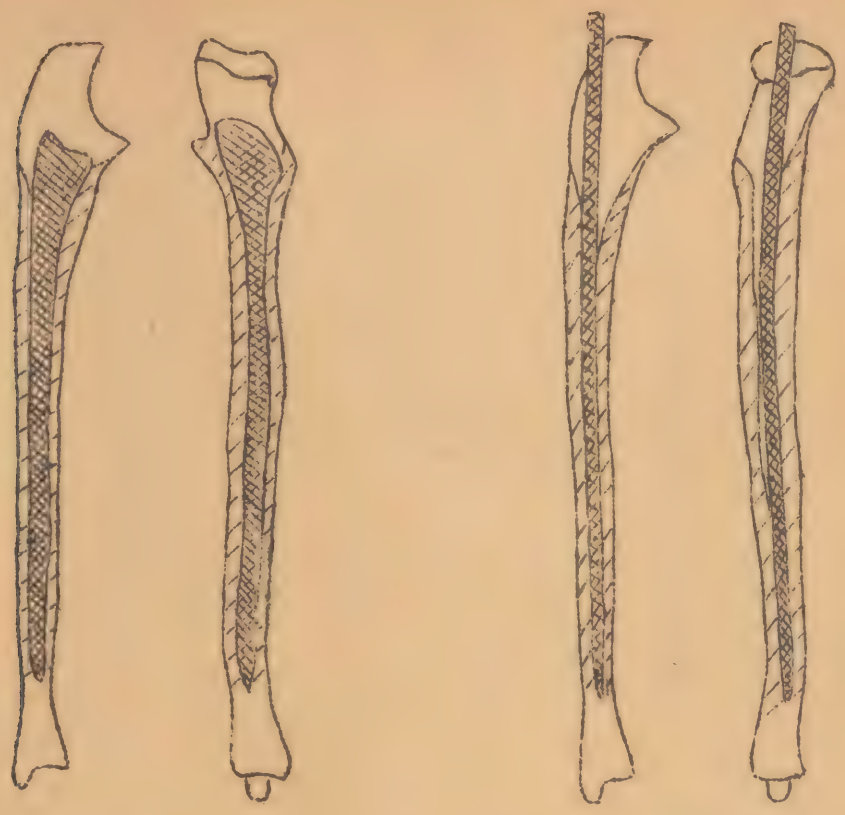
Corresponding procedure in proximal marrow nailing will be possible only if the elbow of the arm is temporarily stretched and the arm rotated in the shoulder joint around its longitudinal axis. However, in most cases this will disturb the reduction considerably, and it will be more practicable to set up another X-ray unit for lateral fluoroscopy, the tube being placed medially to the forearm.

2. Shape of the marrow cavity.

In its proximal third the ulna is wide and towards the shaft it tapers conically. The middle and the distal third are narrow. Close to the wrist the marrow grows wider again. The smallest passage is in the middle of the shaft. Here its width is 2 - 5 mm on an average, and 7 - 8 mm in exceptional cases. The middle part of the shaft is free from spongiosa trabeculae, the extreme parts are closely filled with meshy spongiosa (see ill. III/I).

The marrow cavity of the radius has its most narrow part at the junction of its proximal and median third, from there it gradually grows wider distally. The proximal third is wide throughout its length, it passes abruptly over into the median third. Only the extreme parts of the articular heads are filled with spongiosa. On the

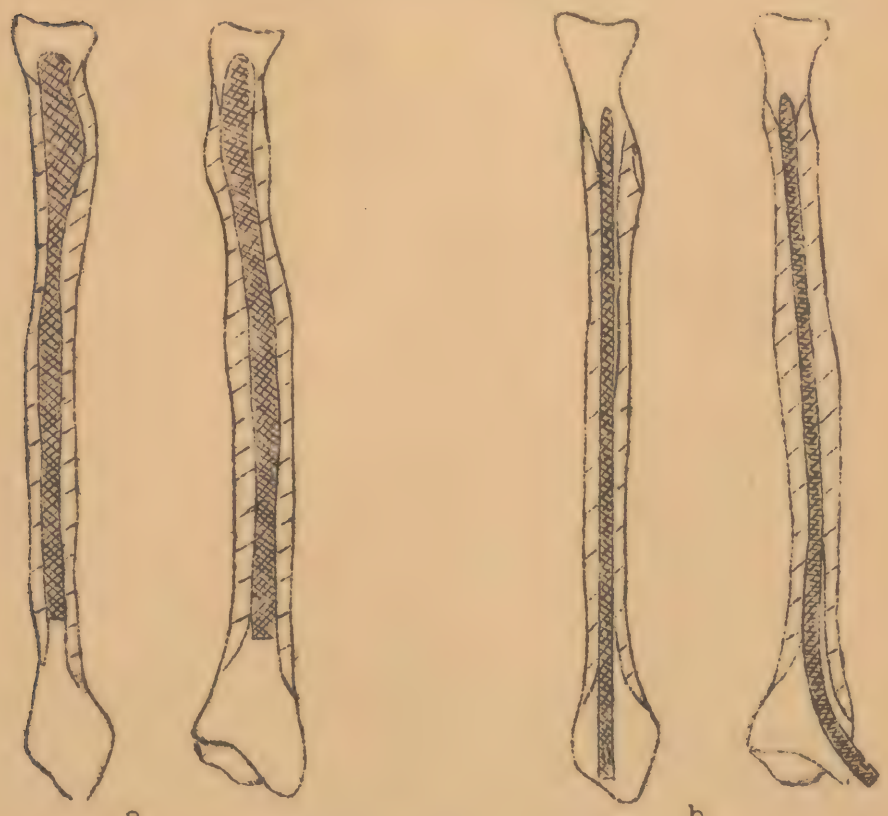
average the most narrow passage shows a width of 2 - 5 mm. In exceptional cases it may be 7 - 8 mm wide (see illustration 111/II).



a b

Illustration 111/I.

a) Marrow cavities of the ulna filled with barium pulp according to EHRMANN.
b) Position of marrow nail.



a b

Illustration 111/II.

a)Shape of marrow cavity of the radius
b)Position of marrow nail in the r adius.

3. Shape of the marrow nail for the forearm.

On cross-section the nail shows the shape of a V. It is on sale in a straight form and is bent into the form required in the individual case by the operator. In length it is 10 - 24 cm., graduated at the rate of 1 cm. The diameters are 3, 3½ and 4 mm (see illustration 112).

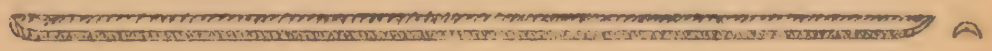


Illustration 112.
Marrow nail for the forearm.

For larger sizes of the marrow cavity nails for the humerus are appropriately bent. Double nails may also be used.

4. Introduction of the marrow nail for the forearm.

Marrow nailing of the ulna.

There are also for the ulna two typical insertion sites, one proximally and the other distally. As in the case of the humerus, the place of insertion has to be as far distant from the fracture site as possible. But fractures located close to the elbow joint will not be united firmly, if nailed distally, because in that region the marrow cavity is considerably widened. Therefore the principle has to be abandoned in this case and the nailing done proximally. R. MAATZ uses a conically-shaped nail adapted to the form of the marrow cavity at this place (see illustration 113).

Illustration 113.
Conically shaped marrow nail for the proximal fracture of the ulna, according to MAATZ.

For proximal marrow nailing only absolutely straight nails are used. They must be chosen as long as possible. Often the evaluation of the X-ray pictures shows that even a marrow nail of 3 mm width is still too thick. Then it is, commensurately to the picture, ground down on a whetstone without any difficulties.

The marrow nail is introduced from the rear surface of the olecranon. In the middle part above that area a longitudinal incision of 2 cm. is made with the elbow in flexed position, and a hole is bored with the awl. The place is a little towards the ulnar side from the mid-line

because the marrow cavity runs in a curve slightly concave to the radius and as the nail is only slightly flexible due to the relatively solid plate material used for its manufacture, on account of its small size. Using an electric drill is very dangerous as thus the corticalis may be pierced. HAEBLER strongly recommends using a large cannula at this place for boring because a probe can be advanced in it to ascertain when the marrow cavity is reached. The spongiosa is here extremely soft and working with a cannula will be very convenient.

A piece of Kirschner wire rounded off is introduced 6 - 8 cm. deep into the hole and it is made sure by fluoroscopic control whether or not the wire is in the marrow cavity. This wire is simultaneously used as a guide rod after one has ascertained beforehand that it fits the groove of the marrow nail well. Otherwise it will get jammed with the nail in the bone tube. Then the shortening is compensated by prolonged powerful traction and the lateral displacement is corrected. The marrow nail, partly advanced over the Kirschner wire as a guide rod, again will prove an excellent reduction implement. If it is shown by fluoroscopic exposure that the wire is in the distal bone tube the nail can be driven in. Often the reduction is very difficult.

For fractures of the forearm the author recommends the following method of reduction:

The ulna can be palpated in its entire length, but the radius only half-way in its distal part. In a fracture, however, the fragment ends cannot be palpated due to the hematoma and edema. But these can be massaged away by intense kneading with the fingers. Then one feels suddenly the fragment ends between the fingers and can fix them accordingly. It will be best to take the fracture between the thumb and index-finger of the right hand and press both fragments together. Thus it will be possible to obtain proper engagement and any appreciable displacement is immediately felt, yet this is not so if the Kirschner wire leaves the marrow cavity. At the moment where the assistant has got the bone ends engaged in this way, by palpation, the operator should push the Kirschner wire forward. He tests again thoroughly as to whether the Kirschner wire strikes the corticalis on the opposite side, or whether it glides down outside the marrow cavity in the soft parts without encountering resistance, or whether it advances in the marrow cavity of the other fragment. Should this be his impression the assistant will have to put his leaded rubber gloves on and he will have to find out by fluoroscopic control whether or not the wire is in fact in the marrow cavity. Should both bones be broken the marrow nail must not be driven in first because on account of its stiffness it will often render the reduction of the other bone difficult. The introduction of the wire into the other bone is better undertaken first in the same way, as described above, whereupon the nails are then introduced into both bones. The same procedure can be applied in certain fractures of the humerus.

BOEHLER suggests the following reduction positions for marrow nailing the forearm:

If there is no dislocation in the distal radio-ulnar joint when both bones are broken in the distal third the forearm is brought into supination, if broken in the middle or distal third into the intermediate position between supination and pronation, and the wrist in the intermediate position between extension and flexion, respectively between radial and ulnar flexion. If only the radius is broken in the proximal third and partly luxated in the radio-ulnar joint the forearm is brought into supination and the wrist in ulnar-flexion. In fractures of the radius in the middle and distal third the forearm must be supinated and the hand flexed, to the ulnar side. In fractures of the ulna alone with a luxation in the proximal joint the central luxation of the radius is removed by longitudinal traction and ulnar flexion, and the luxation of the radius by pressure of the head of the radius.

Distal marrow nailing of the ulna is made through a longitudinal incision on the ulnar side, which runs from the styloid process of the ulna proximally. The process is distinctly palpable under the skin, Here the bone lies directly under the skin and is extremely soft. Following the incision in the skin the hole is immediately bored with the awl, whereby the latter must be placed in a very flat angle. The point of the nail must be curved a little to the ulnar side lest the nail breaks out to the radial side, while being driven in. For the same reason the shaft of the marrow nail must be pressed strongly to the radial side. The hand is flexed radially. Furthermore it is important that the distal nail end is strongly bent to the ulnar side. Otherwise, i.e. if the nail is straight, this end gradually enters the bone and even threatens the wrist. (See illustration 114).

a b c

Illustration 114.
Distal marrow nailing of the ulna.
a) The point of the nail is bent less the radial wall is pierced.
b) The distal end is bent to the ulnar side lest the marrow nail slips into the bone.
c) Bending the marrow nail was omitted and therefore the head of the nail has slipped into the bone and threatens the wrist.

The head of the nail must not project here more than 1 cm. beyond the bone. The skin wound is closed by two sutures or wound clips.

Marrow nailing of the radius.

The radius can only be nailed distally. This operation was first made by R. MAATZ. The method is the same as in distal marrow nailing of the ulna. According to HAEBLER an incision in the skin is made 2 cm. in length on the radial side. The incision runs proximally from the joint surface of the styloid process of the radius. The bone is exposed between the tendons of the extensor - carpi radialis and extensor pollicis brevis and for the other part between the tendons of the long extensors of the fingers. The hole is 2 cm. in length proximally from the joint surface. Here the bone is very soft and can readily be bored with the awl. A. W. FISCHER and R. MAATZ introduce the marrow nail laterally to the styloid process. A skin incision is made starting from the tip of the styloid process of the radius and proximally runs longitudinally. The hole is made at the process. The further procedure is analogous to that in marrow nailing the ulna distally. The marrow nail must even be bent a little more than in the ulna to avoid its entrance into the wrist. If proceeding according to the HAEBLER method such trouble will be impossible.

The distal end of the radius is from nature a little bent to the ulnar side. However, when driving the nail in from the styloid process it must have a marked radial curve. Both curved lines are opposite in direction and therefore distal fractures are thus made to gap a little.

It is also important in fractures of the forearm to get the fragments impacted with full force after nailing. X-ray control has to be made with great care, especially if both bones have been nailed.

5. Further progress.

In most cases a very early start with exercises is possible and supplementary fixation bandages are seldom necessary. Dismissal from the hospital and ambulatory treatment will usually be possible after a few days.

Removal of the marrow nail should by no means be made too early. Frequently the bones of the forearm are very slow in forming callus. Advantageously the nail is removed no earlier than after 6 months, more so as the patients are capable of working to the full extent with the marrow nail in the bone.

6. Faults and risks.

As already mentioned the greatest risk in distal marrow nailing is to perforate the opposite wall of the bone and to a lesser degree entering the wrist. Both hazards

have to be counteracted by giving the nail an appropriate curvature. If the radius is distally marrow nailed the head of the radius may be easily pierced if the nail has been chosen too long. This may easily be overlooked in the fluoroscopic exposures because the view is impaired by the contours of the ulna.

7. Examples.

Marrow nailing of the forearm may be demonstrated by the following examples:

Due to a fall in the street the 83 year old patient E. G. suffered a fracture of the radius and ulna of the right arm, a hand's breadth above the wrist. Both bones were to be nailed distally under a plexus anesthesia. First the reduction was made by manipulative traction. Due to the very thin arm the result of the reduction could be very well checked by palpation through the skin. Then the holes to introduce the nails were drilled with the awl and once again the reduction was checked by palpation. Without meeting great difficulties two Kirschner wires were introduced, by merely following the sense of feeling. Fluoroscopic control showed the wires in the right position. The marrow nails were driven in in the usual way over the wires, the wires were removed and the skin wounds closed (see illustration 115).

a b c

Illustration 115.
Double fracture of the forearm in the 83 year old patient E. G.
a) before the nailing
b) immediately afterwards,
c) 3 months later
d) 8 months later, after removal of the nail (illustration 115 d see next page).

115d 115d

No splint was applied. Exercises were started the next day. Dismissal from the hospital after two weeks. Re-hospitalization 8 months later to remove the nail. Complete freedom of motion. After the nail had been removed the fracture was in an ideal position and stable.

Illustration 116 shows the X-ray picture of a marrow nailed forearm where the radius was nailed distally and the ulna proximally.

a b c

Illustration 116.
Fracture of radius and ulna. Radius nailed proximally, ulna distally.
a) before marrow nailing
b) immediately afterwards
c) after extraction of the nails, 6 months later.

a b c

Illustration 117.
Fracture of radius and ulna. Radius nailed proximally, ulna distally.
a) before the nailing
b) immediately afterwards
c) 6 months later.

g. Percutaneous marrow nailing of the clavicle.

There are various methods of treatment for fractures of the clavicle. This proves that none of them is considered entirely satisfactory. It is similar with the marrow nailing of fractures of the clavicle. This also yields excellent results, it is true, but in technical respects it is very difficult for the following reasons: Firstly, it is anything but easy to obtain accurate reduction because there is frequently still a third fragment which makes judging the reduction more difficult. It will not be possible to fluoroscope in two planes at a right angle one to the other due to the form of the thorax. Finally it is a difficult task to drive the marrow nail ahead as the shape of the clavicle is double curved like an S and the marrow cavity is filled with solid bone trabeculae.

Position of the patient.

The patient lies in the dorsal position, the arm abducted, so that fluoroscopy with one tube placed below the patient is possible. The second tube is placed in the axil-

la and it projects a tangential view of the thorax, in which the clavicle is considerably distorted, upon the screen which is fixed upon the shoulder; that is the mode of fluoroscopy according to RANDENWALDT. A large operative area extending from the shoulder to the sternum is painted and draped. The reduction is made under fluoroscopic control. It is greatly facilitated by massaging away the hematoma at the fracture site. Thus the fragments can better be located by palpation than is possible by observing their position on the X-ray screen, since the anterior surface of the bone all along its extent can be palpated under the skin. An incision 2 cm. in length is made above the clavicle along the line of its course and about 2 - 3 finger's breadth laterally from the sternoclavicular joint, and then the bone is exposed. In the middle part of the bone a hole is bored with a 3 - 4 mm drill. The hole runs obliquely towards the shoulder and opens the marrow cavity. A 2 - 3 mm V2A wire is introduced into the hole with the drill and under fluoroscopic control is driven ahead into the distal fragment. Care must be taken that the wire does not pierce the corticalis of the distal or proximal fragment and move outside of the marrow cavity. In most cases a V2A wire of such size will serve perfectly the purpose as a marrow nail. Only in wider marrow cavities may a thin leg marrow nail be useful.

The author advances the wire through the clavicle until it pierces the posterior surface of the shoulder convexity. Therefore the skin there must be disinfected likewise. Then the wire is bent at a right angle at a distance of 1 cm. from the tip. Illustration 118 shows an example of a marrow nailing of the clavicle.

a

b

c

Illustration 118.
Marrow nailing of the clavicle.
a) before the operation
b) immediately after nailing
c) 5 weeks later.

Percutaneous marrow nailing of the metacarpals and fingers is easily performable but indication for it may be given even more infrequently than for the clavicle because these parts heal in traction or plaster casts both rapidly and well.

Rather marrow nailing will come into consideration for osteotomy. It can be performed easily. (See chapter VI).

h. Removal of the marrow nail.

There is no uniform opinion among experts in nailing the neck of the femur whether or not the nail has to be removed after the fracture is healed. Many surgical clinics, such as Kiel, hold the view that the nail can be left for a lifetime and need only be removed if discomfort arises. Yet that is very infrequent (see chapter II). In many cases femur neck nails have been left for more than 10 years and their presence is not felt in any way. SVEN JOHANNSON removes them only in exceptional cases.

However, in the case of the marrow nail one is unanimously of the opinion that it has to be removed again. If only for reasons of feeling one has scruples against leaving such a large foreign body permanently in the body although it very seldom wanders into the nearby joint. Generalized injuries caused by the metal have not become known. Even if the nail grows rusty this need not necessarily lead to disorders in the surrounding tissue because a firm layer of connective tissue is formed around the marrow nail early and encloses it. Sometimes the patients did not agree with the removal of the nail and objected that they had no complaints and no desire to undergo another operation for the purpose in question. Patients suffering for a prolonged period from pseudarthrosis of which they had been healed by marrow nailing expressed repeatedly the apprehension that after removal of the nail the former condition might return and on account of that argument opposed the removal of the nail. One of the patients of the author has kept his marrow nail already for 7 years for that reason. He has not had any discomfort although it is pretty certain that the nail has grown rusty in that time. It is a big double nail (Y-nail) in a subtrochanteric fracture. Such double nails will always grow rusty if left for a prolonged period, due to friction at the crossing point (see chapter II and III).

With the exception of these rare cases most patients are quite ready and willing to have the nail removed, especially if from the outset their attention has been drawn to the matter.

The marrow nail must not be removed before the fracture is entirely healed by bone. The appearance of infection can never be an indication to remove the nail!

Removing the nail for that reason means to abandon the advantage of an absolute immobilization of the fracture, to favor the infection, and in most cases to spoil the outcome of the reduction. By an intervention an infection may be promoted directly. In an infected fracture the marrow nail acts as a drain (see chapter VI and VII). Removing the marrow nail on account of an infection must be regarded as a serious mistake!

Premature removal of the marrow nail may be justified only if the X-ray exposures show that the nail was driven in wrongly from the beginning and that it is no longer located in the marrow cavity of the proximal or distal fragment or it is revealed that a "stable osteosynthesis" was not obtained. If the fragments have become disengaged in motion the nail may have to be replaced by another one larger in thicknes or length. As already mentioned it also happens once in a while that the nail wanders and threatens the adjacent joint or even has already penetrated into it. (See chapter II and IV). It may also be that the nail has bent or broken (see chapter II),

But all these are rare exceptions. Ordinarily the marrow nail is removed only after it is absolutely certain that the callus has become firm. It is extremely difficult to find this out. Routine clinical practice in order to ascertain whether or not the fracture is still elastic cannot be applied in marrow nailing. The nail impedes any springiness of the fracture. For the same reason we cannot ask for a statement made by the patient as to whether or not he has a feeling of firmness in the fracture. There is nothing else left but to come to a judgement on the basis of the X-rays. This is laborious and needs much practice. Fluoroscopic exposures are useless in this case. The X-ray picture shows the density, the structure and the contours of the callus. Exposure conditions being equal the contents of calcium in the callus is reflected in the varying density of the shadow of the callus. But the firmness of the bone and also of the callus is not dependent on the calcium content. Thus MASON could not find any correlation between firmness of the fracture and calcium content. ROESSLE also found no relation between the hardness of the bone and its calcium content. More significance has to be imputed, according to REISS and BLOCK, to the content of water in the bone as well as in the callus. Being richer in water means having a greater elasticity. The density of the shadow of the callus should therefore be judged very cautiously. Most significance has to be attributed to the structure as well as amount of the callus formed. It will be most advantageous to wait until symptoms of resorption can be recognized on the callus towards a reduction of the callus luxurians and change into the definite callus. The cloudy and radial structure is then gone. The osteon tracts are longitudinally lined up, the tips and jags are reduced. After some time this change has also come to a close. As the reduction in marrow nailing is commonly correct to the millimeter the site of the fracture can hardly be located again. The nail does not in any way impede that interchange. With the calcification and ossification of the callus the bone has regained its mechanical function. At that juncture

the nail has transferred its function to the bone. It has become loose and is surrounded by a layer of connective tissue. The loosening does not go as far as to enable transverse dislocation of the nail. It can only be moved a little more readily to and fro. However, as the bone is only longitudinally strained, the nail is thus relieved of its functions. The transformation to the ultimate callus takes place in the same form as if there was no nail at all. This proves at the same time the correctness of the view stated in chapter III about the structure and the functions of the bone. As an illustration the fracture of the humerus of the 26 year old G.V. may be demonstrated. He suffered from a fracture of the humerus of the right arm due to an accident, and was treated by closed marrow nailing. The marrow nail was removed only 1½ years later. On the X-ray the fracture site is hardly recognizable (see illustration 119).

Illustration 119.
Immediately after removal of the marrow nail. The cleft of the fracture cannot be recognized any longer.

A similar case is demonstrated in chapter II where a leg marrow nail was not removed until after 1 year.

With the exception of those very infrequent cases where a wandering of the nail occurs one need not mind leaving the nail for a prolonged period of time in the marrow cavity. Considering the roentgenological difficulties in judging the stability of the fracture it will be of advantage to wait for safety's sake even a bit longer. Impressed by the rapid exuberant growth of the callus the author suggested in his first publication to remove the marrow nail even after 8 - 10 weeks. But he experienced a break of the callus. In a closed fracture of the femur the marrow nail had been removed after 9 weeks because there was plenty of dense callus. 3 days later the patient got up whereupon the leg bent. The callus was broken. (See illustration 120).

The patient made immediate active exercises with the leg as he was accustomed to do because he had walked about since the 3rd day after the marrow nailing. After the nail had been removed it was immediately introduced anew which could be accomplished without further difficulty and without having to expose the fracture. In most cases it is quite easy to re-introduce a nail because it is introduced through a preformed slot which is easily found again. This time the

nail was not removed until after 3 months and then the fracture was found to be absolutely firm.

Considering the experience the author made he now suggests to wait as long as possible and to remove the nail no sooner than 4 - 6 months afterwards. There are also no objections to wait even 8-10 months, more so as throughout that period the patient is fully capable of working. The date for the removal of the nail may largely be adapted to special wishes of the patient, e.g. if he contemplates to combine it with a holiday.

In the marrow nailing of infected fractures, or following upon pseudarthrosis, etc. a very slow progress in the solidification of the fracture is often observed. In such instances one must wait very much longer for the removal of the nail. The appearance of a fistula must not be a temptation to remove the nail. By no means should the nail be removed in febrile or severe inflammatory conditions. This has to be postponed until symptoms have subsided again (see chapter VI).

Illustration 120.
Break of the callus due to premature removal of the nail. In a closed fracture of the femur the nail was removed as early as 9 weeks after the operation which caused the callus to break. Uneventful healing followed after another marrow nailing.

In children an earlier date of removal may be fixed, as the healing of fractures, as is well known, proceeds very much faster than in adolescents.

BOEHLER recommends as the most favorable date for the removal of marrow nails 6 - 7 months after the operation.

There is still another point which may make it advisable to remove the marrow nail as late as possible. After 3 months the nail grows looser in the marrow cavity. While the application of 200 - 300 kilograms of traction power will be necessary to remove a recently introduced marrow nail of the femur only a few kilograms are required, or only a fraction thereof, after a lapse of 4 months.

As to the operation of removal, it is only a minor one. It can be made under local anesthesia as the marrow cavity is absolutely insensitive. BOEHLER on principle undertakes the removal of the nail under local anesthesia. Many surgeons use evipan narcosis.

Although this operation is only a minor one - BOEHLER undertakes it in most cases in out-patient treatment - it must be prepared carefully. First of all the instruments which are needed must all be available. The removal of the marrow nail may fail unless the respective special instruments are at hand.

The nail is removed by making an incision 2 cm. in length in the skin. It must be born in mind that only in exceptional cases is the head of the nail located at the place where it initially was inserted. For the nailing was done with the joint in a distinct position. In the final phase a ram was used and thus the head of the nail ultimately got some centimeters away from the skin wound. For instance the marrow nail of the neck of the femur is driven in with the hip joint in flexion and adduction. If the patient is then in an upright position the place of insertion through the skin will be far posterior to the head of the nail (see illustration 121).

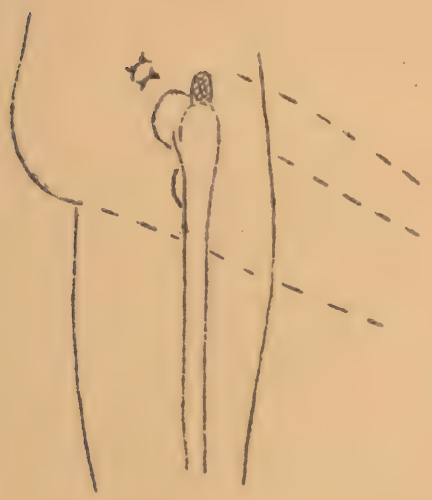


Illustration 121.
The place of insertion of a marrow nail of the neck of the femur in relation to the place where the head of the nail is located when the patient is in an upright position.

If the humerus is concerned the head of the nail wanders according to inward or outward rotation (see illustration 122.

Illustration 122.
The head of the marrow nail wanders under the skin according to inward or outward roation of the arm. The position of the head is indicated by a cross. (According to high frequency localization).

Consequently it will be necessary to mark the position of the head on the skin before making the incision, and after this marking has been done the joint must not be changed any more in its position otherwise the marking will no longer be correct. Infected fractures form an exception from this rule as there the nail serves simultaneously for the fixation and drainage. Often a fistula is also present which leads directly to the head of the nail. Sometimes the head of the nail can easily be located under the skin by palpation. But one can also easily be misled in that case by a projecting part of the bone. In order to localize the head of the nail BOEHLER uses an X-ray unit with a wire net according to JAESCHKE. A wire net is spread out over the neighborhood of the insertion

place. Then the picture shows the head of the nail in a certain quadrant of the net (see illustration 123).

Instead of using a net it has also proved in practice of good use to pin the head of the nail using a fluoroscopic screen.

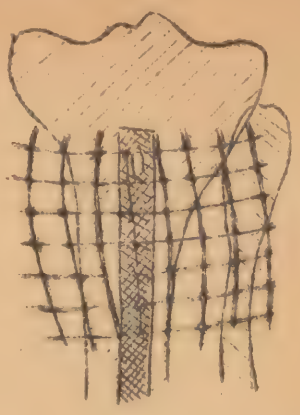


Illustration 123.
Wire net according to JAESCHKE for roentgenological localization of the head of the marrow nail. The head appears in a certain quadrant of the net.

The author uses the high frequency method which from 1930 onwards he has used to trace foreign metallic matter in the body. An appropriate device has been developed in cooperation with the firm of SIEMENS and it has proved in wartime of very good use in several thousands of operations performed to remove shell splinters. However, in this case the difficulties in tracing these bodies are even greater. Localization by the X-ray often fails in spite of expensive and complicated appliances. In the course of the operation the foreign body shifts due to the molding by the fingers or instruments and it cannot be found anymore at the place indicated by the X-ray.

Fluoroscopic control will fail in all those cases of insufficient contrasts where either the foreign body, on account of its small size (needle) or permeability for rays (light metal) does not yield sufficient opacity or the surrounding district on account of extensive soft parts or solid bone accumulation throws too much opaqueness. Fluoroscopic control during the operation is time consuming and troublesome on account of the adaptation needed. The operator is threatened due to insufficient protection from irradiation and so is also the asepsis due to the blackout. For all these reasons the solution of the problem by high frequency electric waves is very fine and permits the use of a handy, easily manageable appliance shaped like a small radio set. Enclosed in the tip of a probe is a small coil that is connected by cable with the appliance itself, consisting of an inductometer of extreme sensibility with built-in loudspeaker and alternating current (lighting-circuit) supply. If any metal matter comes within the range of the field of the coil the latter will change its inductivity and this is made audible by the loudspeaker as a change in its tone, due to interference with a constant high frequency oscillation-circuit. The closer the probe approaches the metallic foreign matter the higher pitched the sound becomes. Thus the foreign body will be "heard" even a few centimeters away from the probe. This is an absolutely simple and reliable means for locating foreign bodies. All kinds of metal will be indicated and this is important in the removal of splinters of light metal which are particularly dangerous and often are not visible under X-ray exposure. Even minute shell splinters, broken needles, etc. will be indicated (see illustration 124).

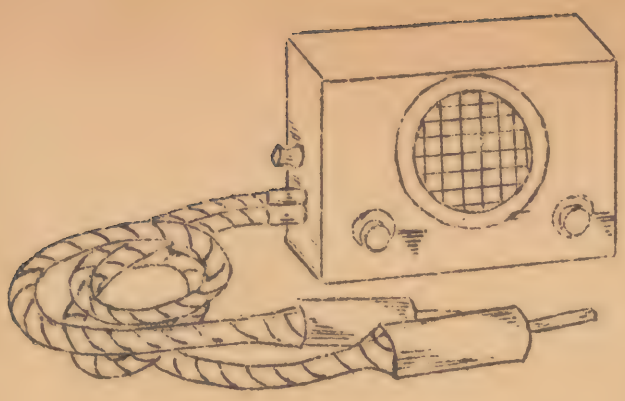


Illustration 124.
High frequency metal detecter of the firm of SIEMENS-REINIGER WERKE, devised by KUENTSCHER to trace the head of the nail.

Manipulating this contrivance for nail removing is as follows: The patient is placed in position and the dermal point of proximity of the nail is determined by pressing over the skin with the probe of the apparatus in the vicinity of the insertion site of the nail. The place where the change in tone is the most marked is the dermal point of proximity and it is marked by a moistened silver nitrate pencil. After the operative field has been iodized the mark shows up as white silver iodide. In sensitive skin it will be better to do the marking with a solution of Methylene Blue. Care must be taken to prevent any change in the position of the joint, otherwise the marking will not remain correct. If all the same a change happens, the mishap will not be too great because the probe can be sterilized and if the head of the nail is not found instantly the probe can be introduced into the wound. But previously all metal instruments have to be removed from the range of the operative field.

Implements to remove the nail.

Quite a number of instruments have been recommended to remove the nail. The author used first a simple winch by which a wire which had been threaded in the eye of the head of the nail was wound up. The implement was placed upon the bone (see illustration 125a). A disadvantage was that the wire frequently tore off. Besides the implement easily pierced into the bone. An excellent device has been constructed by POHL. It consists of hooks varying in size that are to be inserted in the eye of the nail. The hook is furnished with a handle. With the left hand one exercises a strong pull on the nail. With the right hand one strikes simultaneously with a slot hammer on the striking surface of the handle. It is of utmost importance that the weight of the hammer used for driving the nail in is less than the weight of this hammer for removing the nail, 650 grams, because otherwise it may become impossible to retract a nail recently and vigorously driven in (see il-

lustration 125b). STOER has recommended a device working according to the same principle. As a hammer a centrally perforated metal piece is used.

J. BOEHLER has suggested a clamp which prevents the hooks from slipping out of the eye of the nail.

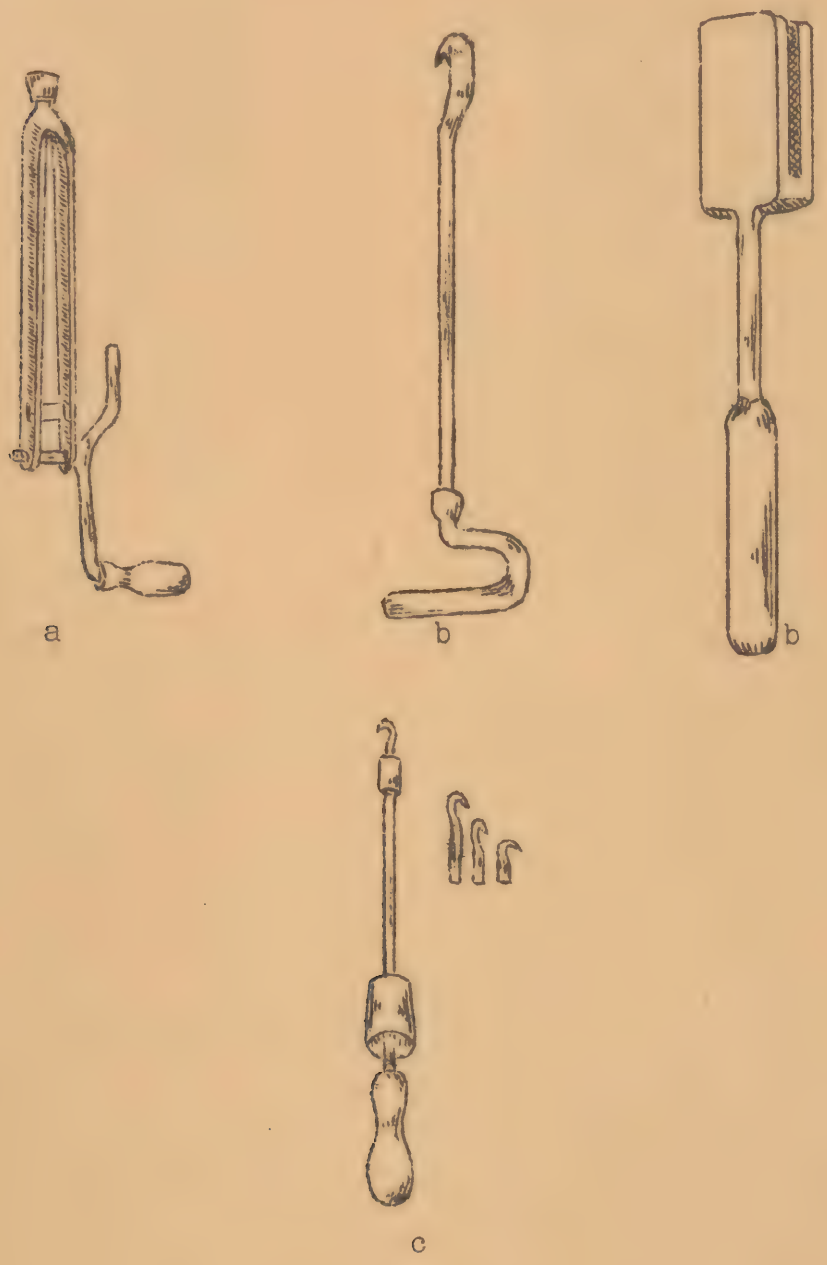


Illustration 125.
Implements to remove the marrow nail.
a) winch according to KUENTSCHER
b) hook and slot hammer according to POHL
c) removing implement according to STOER.

These devices can be used for all marrow nails. In very exceptional cases, it is true, the removal of marrow nails of the femur which have been recently driven in may fail. The author recommends in these cases a screw traction apparatus which he has constructed according to the Smith-Petersen device for the removal of marrow nails of

the neck of the femur. POHL made an improvement by adding a spring (see illustration 126).

Illustration 126.
KUENTSCHER/POHL screw traction device for removing the marrow nail.
a) Screw traction with hammering appliance
b) separating shim
c) extension

A solid steel bolt is carried through the eye of the nail. Simultaneously this bolt is carried through the end piece of a male screw. By tightening the male screw strong pressure is exercised on a solid steel spring. This pressure can be read off from a dial. Then a hook is fitted to the eye fixed to the other end of the screw and thus the nail is struck out. In order to prevent the device from piercing too deeply into the bone a strong separating shim is inserted which is calotte shaped and therefore guarantees good fitting even if the nail is not at a proper angular relation to the surface of the bone. If the nail cannot be moved further after only a short distance an extension must be inserted between the device and the linking parts. If care is taken to not use too heavy a hammer and to cease hammering when the nail can only barely be driven in or does not go forward at all this device will hardly ever be needed.

Sawing the nail off.

If this device is not available immovable nails must be sawed off. This must also frequently be done instead of changing the nail if the osteosynthesis is stable but the nail is too long and projects from the wound. Therefore in all marrow nailings a metal saw must be available. If after some months these nails have grown loose they may readily be removed by means of pliers on which one strikes with a hammer. H. GRIESSMANN has referred to a special kind of pliers which grasp the nail well and permit removing it easily. (See illustration 127).

If there is the little cap on top of the marrow nail which has been described in chapter III it must be taken off which will easily be possible by using a raspatory. By moving the cap aside the marrow nail can often be removed without further difficulties. Then the cap can be left at its place. If it becomes necessary to remove it this will not be an easy matter because it is grown to the surrounding muscles and connective tissue.

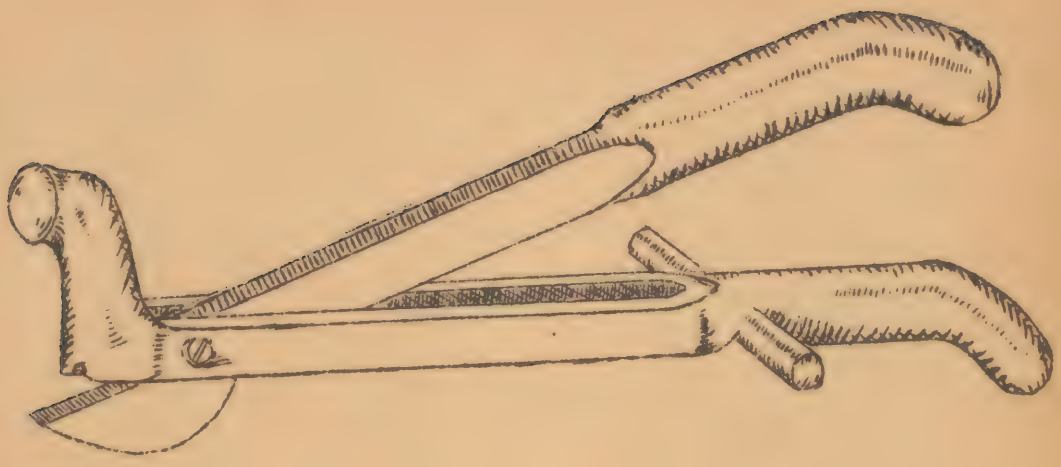


Illustration 127.
GRIESSMANN pliers for the removal of marrow nails with the eye sawed off. The pliers are driven back with the hammer.

Frequently the removal of the nail is difficult because it was driven in too deeply. Then the nail is more or less overgrown with the bone and must be exposed with the raspatory or chisel. The awl too may prove useful in that instance, especially in exposing the groove of the nail.

In spread nails of the leg with a wedge the inside nail must always be removed first. Otherwise the removal will be impossible or the bone will be broken.

The removal of bent or broken nails.

If a nail has got bent its removal appears at first a very difficult task, especially if the femur is concerned. Yet this is not so. By applying powerful traction to the head of the nail straightening to a certain extent can be achieved. The wording of the technician reads: "The nail is straightened in the hole". Additionally this straightening can be supported by bending an extremity by the help of one or several assistants. It will also not be difficult to introduce into the old bed of the drawn out nail a new and straight one and thus exposing the fracture is avoided.

If a broken nail has to be removed the proximal end is first struck out as usual. If the femur is concerned the distal part is then removed by introducing the POHL hook with stick, 75 cm. in length, to serve as a nail catch. Under fluoroscopic control it is advanced until it strikes the nail and then it is rotated by its axis until the hook glides ahead in the slot of the nail. After passing the point of the nail it is given once again a turn and then this part of the nail can be safely drawn out. (See illustration 128).

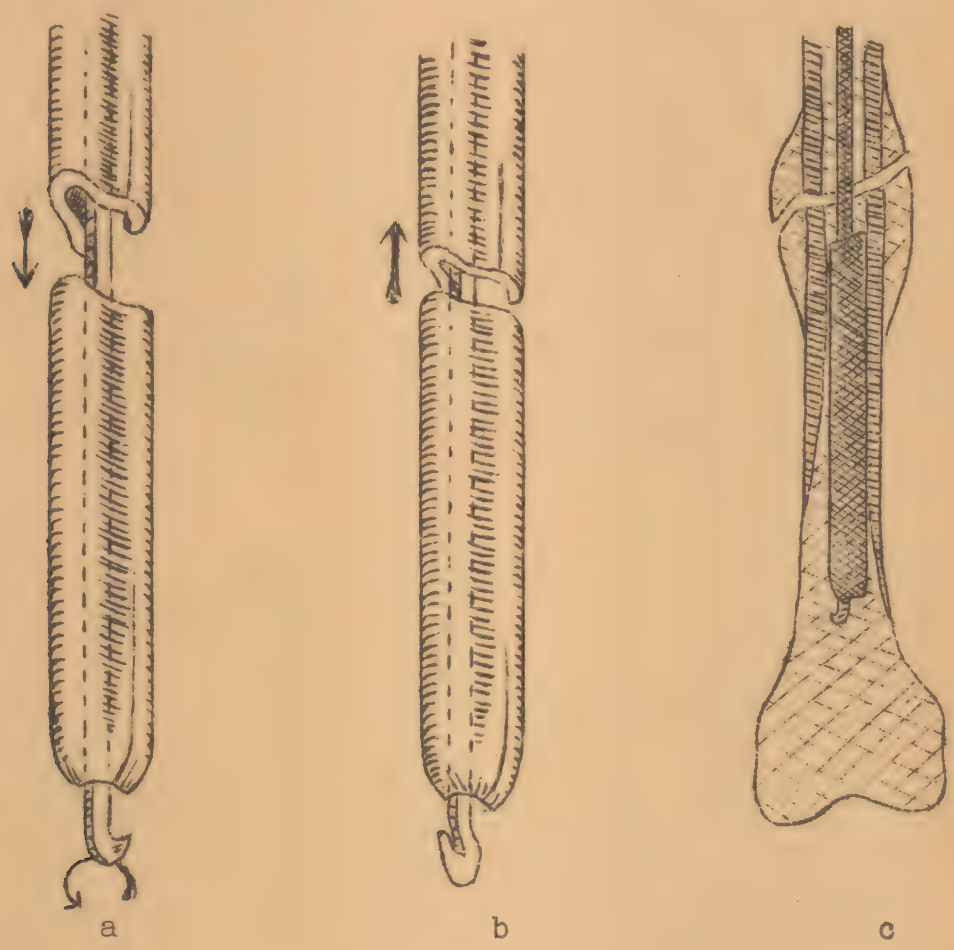


Illustration 128.
Nail catch to remove the broken nails,
a) position of the hook when being introduced on cross-section of the nail,
b) during the removal,
c) X-ray of the nail catch during the removal.

In the case of all other kinds of marrow nails the nail catch is introduced with the point of the hook turned towards the nail. It hooks in behind the point of the nail just after having passed along it. In legs it will frequently be necessary to expose the point of the nail by making an incision on the anterior edge of the tibia whereby the high frequency finder will be of good use. Thus the exposure of the fracture site is avoided.

In removing bent or broken nails care must be taken that any displacement that has occurred is corrected. Usually it is only a bending which can be remedied by simple stretching.

In aseptic cases the wound is closed by 3 or 2 sutures after the removal of the nail. In infected fractures it has to be left widely open.

Faults and risks in removing marrow nails.

There will not be any danger if the directions stated previously are given careful consideration. Of course it may happen that following upon aseptic removal of the marrow nail and suturing an infection may develop in the wound. But this may not have any serious consequences. There is only one case known in the literature where after removal of a marrow nail of the leg an abscess appeared at the fracture site, which, however, healed after some weeks without doing any harm (GRIESSMANN and SCHUETTEMEYER). Apparently the layer of connective tissue which envelops the marrow nail prevents the infection from spreading to the marrow cavity and bone. Of course, at the first indication of such an infection it is necessary to remove the sutures immediately.

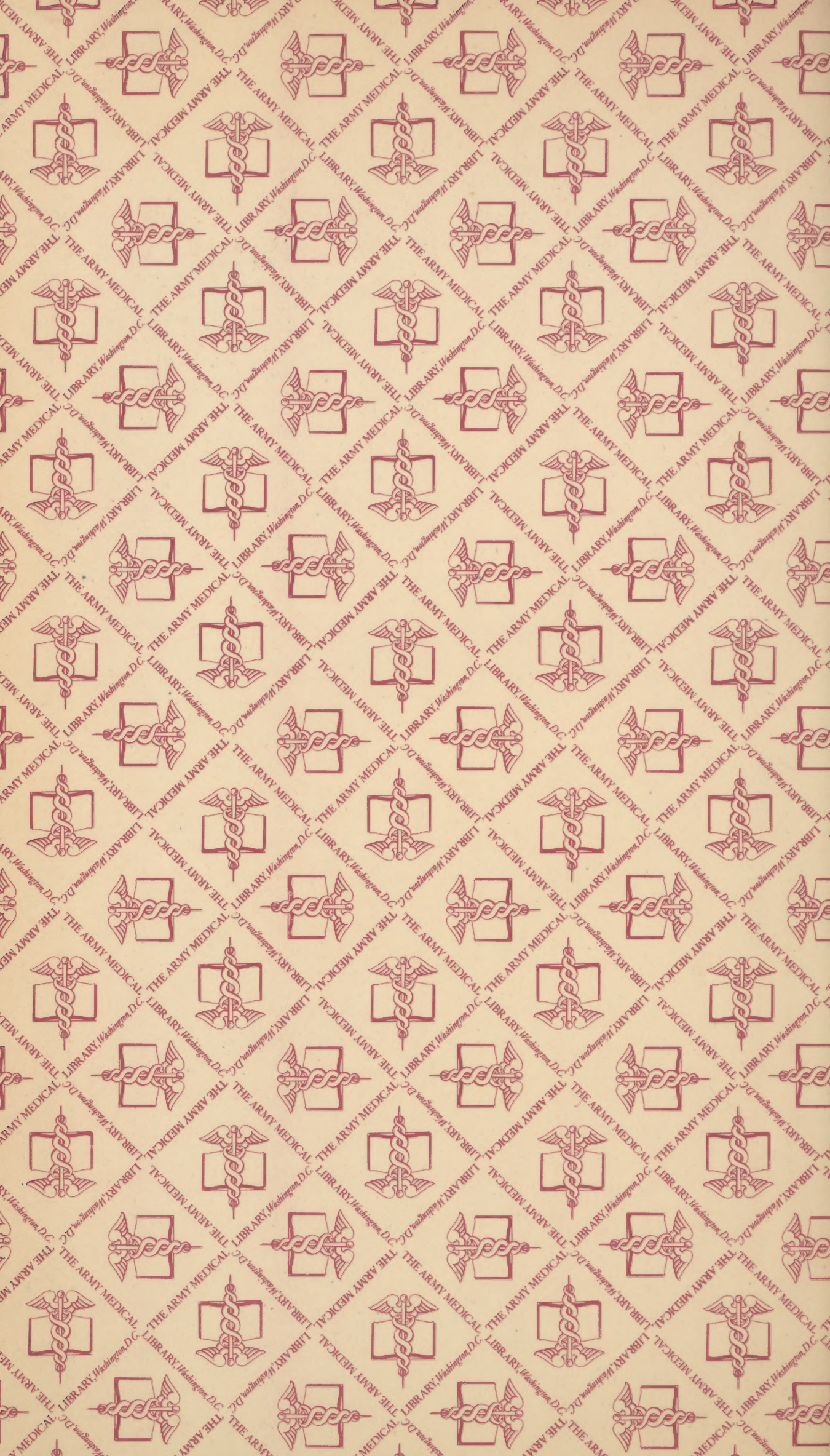
If it is omitted to locate the head of the nail, or the search for it is not made in a cautious way one runs the risk of exposing the nearby joint. Such a case has been reported by the Kiel surgical clinic. It referred to a patient with bilateral fractures of the femur which functionally and anatomically had healed excellently. One year later when the nails were removed this process met with difficulties on one side because the nail was too short and stuck deeply in the trochanter major. The latter had to be exposed widely by the chisel, whereby the capsule of the hip joint was injured. An infection of the wound resulted with a hip-joint edema. The patient died of this infection. The deplorable incident might have been prevented by the use of a longer nail and possibly a detector.

Usually search of the head of the nail is made too far medially and thus the operating surgeon reaches eventually the region of the capsule of the hip-joint on the neck of the femur. Among the other joints there is only danger for the wrist in removing the nail of the radius, especially if the head of the nail was not given the indicated radial curving before it was driven in.

Finally another case of death may be reported. In an infected fracture of the femur the operator had to expose the bone to a wide extent laterally, and after having taken this tremendous trouble succeeded in removing the nail although proper instruments were not available. All his endeavours to do with the routine set of instruments such as dressing-forceps and bone cutting forceps had proved a failure although the nail was in its place as long as 6 months. A few hours after the operation the patient died of symptoms of operation shock. One can hardly blame the method for

this fatal issue, rather the lack of an appropriate set of instruments has to be made responsible.

If in the course of marrow nailing the nail got jammed the efforts of the operator to get it loose and to remove it may really reach a dramatic phase. If the large removing device mentioned previously should not be available, it may be better to stop the operation rather than endanger the patient with severe operation shock, due to prolonged pulling, hammering, pushing the nail forward and backward, and extending this over many hours. In such a case the nail has to be sawed off, or if even a metal saw is not available the nail may be left extending beyond the wound. It can be sawed off later or one can even wait until it has become loose after 3 - 4 months and then it can be removed easily.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